THE INFRASTRUCTURES OF EQUITY AND ENVIRONMENTAL JUSTICE

A Dissertation

by

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ABSTRACT

An infrastructure crisis exists in America with a prevalence of systems in disrepair. While this problem has been documented, limited research has asked whether the infrastructure crisis overburdens certain population groups. Through a series of three conceptually linked papers, this dissertation investigates the inventory, condition, and distribution of stormwater and roadway infrastructure systems using the frameworks of equity, environmental justice, and social vulnerability to assess racial and economic disparities in infrastructure provision across neighborhoods. This dissertation includes a literature review and two empirical papers to link these bodies of research—equity, environmental justice, and social vulnerability to disaster—to planning inequalities in infrastructure management. These papers make some of the first empirical assessments of infrastructure disparities based on race, ethnicity, and class.

In “Unequal Protection Revisited,” I develop the theoretical framework to integrate environmental justice and social vulnerability to disaster theory within a critical examination of infrastructure. In paper two, “Waterproof,” I use open ditch stormwater systems data from Houston, Texas consisting of an inventory of 2,400 miles of roadside open ditches to understand variation in location and amount of open ditches across Census block groups. Open ditches are particularly limited in discharging stormwater to protect people and mitigate the inundation of property, especially in urbanized areas. Findings indicate that communities of color are more likely to have open ditches and have a greater proportion of their roadsides equipped with open ditch systems. Race was

the strongest predictor of the proportion of roadside open ditches controlling for median household income, population density, neighborhood age, housing improvement values, and vacant homes. Lastly, in paper three, "Pavement and Prosperity, I use roadway condition data from the City of Houston to compare conditions across Census block groups. The findings are contrary to transportation equity and environmental justice theory such that communities of color were found to have marginally better road condition ratings relative to the other neighborhoods, nevertheless most neighborhoods had low ratings in terms of acceptable pavement condition.

These findings reveal opportunities for the rehabilitation of transportation systems and the retrofitting and replacement of stormwater infrastructure systems to green infrastructure or low-impact development standards as a method to increase environmental justice and reduce inequities in infrastructure provision and resulting environmental impacts**.** This research indicates that outdated, insufficient, and declining infrastructure systems might be more prevalent for minority communities across the U.S. Collectively, this research shows the need for a continued environmental justice research agenda that addresses the planning, management, provision and distribution of infrastructure systems to improve neighborhood wellbeing and urban utility for communities across the country, especially communities of color.

DEDICATION

To all the black and brown kids of the Furr High School Green Ambassadors on the east end of inner city Houston, this dissertation is dedicated to you all. Keep up the amazing work and the fight for environmental justice for all. You all are truly the next generation of ambassadors for the movement.

#blacklivesmatter

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CHAPTER I

INTRODUCTION

"The Infrastructures of Equity and Environmental Justice", grew from an interest in understanding how environmental injustices and hazard vulnerabilities are theoretically connected in the context of public infrastructure. An infrastructure crisis exists in many American cities which has led to the prevalence of antiquated and systems in disrepair. Critical infrastructures consist of man-made systems that function to produce and distribute a continuous flow of essential services towards social welfare, such as energy, transportation, emergency services, and water systems, among others. Communities of color and inner city neighborhoods particularly may be unequally managed and protected by these declining infrastructure systems.

The prevalence of this infrastructure phenomenon has been linked to larger planning and development patterns (i.e. urban sprawl and outmigration, segregation, disinvestment and urban decay) shaped by power and privilege that create pockets of disadvantage and prosperity. However, other analyses from the well-developed bodies of literature of equity, environmental justice and social vulnerability suggests that these trends are not simply a byproduct of these larger planning phenomenon; related to but a deeper narrative. Essentially, this work looks at how the societal distribution of critical infrastructure that can affect daily environmental conditions and vulnerability. Thus infrastructure systems can produce differential impacts from environmental extremes, such as flooding. In the environmental planning literature, the current prominent paradigm is the Environmental Justice approach, which describes how some individuals, groups, and communities receive less protection than others because of their race, ethnicity, national origin, and economic status. Moreover, low-income communities and communities of color bear a disproportionate burden of the nation's environmental problems and occupy spaces where built environments are the opposite of prosperous. In the hazard mitigation and disaster planning literature, the current prominent paradigm is the Social Vulnerability approach, which describes how social stratification based on race, income, disability, gender, age, nationality, among others contributes to differential risks and impacts from disasters. These understandings are now being questioned by the rising political and academic interest in these more urban issues such as in how residential segregation can have consequences for communities of color in light of climate change and increasing exposures to environmental hazards. However, there has yet to be any published discussion of how these two well-established bodies of literature in Environmental Justice and Social Vulnerability can be merged to expand our understanding of emerging global environmental problems. Likewise, there has been little if any discussion around the provision of infrastructure as well as the designation of maintenance and rehabilitation funding in our capital improvement plans and programming as a mechanism to modify vulnerabilities and environmental outcomes.

In this dissertation, through a series of three conceptually linked papers, this research addresses three fundamental questions: (1) what is the general inventory, condition, and distribution of infrastructure systems; (2) how do social variables associated with equity, environmental justice, and social vulnerability (e.g. race, ethnicity and class) drive the inventory, condition and distribution of critical infrastructure at the neighborhood level; and (3) are there spatial associations in infrastructure condition and distribution at the neighborhood level, and if so, what spatial regression models best account for these associations? Based on a literature review and analysis of two infrastructure datasets from the City of Houston, Texas, the findings are organized around the distribution of infrastructure systems and conditions and the statistical methods that can best model these infrastructure data, resulting in one paper that provides a conceptual framework for carrying out this work and two empirical results papers.

In paper one, "Unequal Protection Revisited", this research reviewed key literature, examined conceptual frameworks, and raised issues around critical infrastructure that are not adequately addressed by existing hazard vulnerability and environmental justice literatures. This work showed how fundamental principles of Environmental Justice can bolster and compliment those of Social Vulnerability. The findings and conceptual framework provide in-depth insight to how neighborhoods are not inherently vulnerable and that individuals don't prefer to live in environmental justice communities. As previously stated, there are certain social processes and larger planning and development patterns shaped by power and privilege that create pockets of disadvantage and prosperity. These same forces led to early racial zoning and later segregation and isolation of minority racial groups that resulted in deflated tax bases and built environments in disrepair. The hypothesis is that environmental prosperity or demise is a direct result of social vulnerability in terms of neighborhood race, ethnicity, and class and the built environment is exactly the physical manifestation of social circumstances that have been alluded to in both the disaster and environmental justice literatures. Therefore, this research pronounces that physical and engineered settings have to be explored with a progressive lens that views built features as a continuation of social circumstances for a comprehensive and robust understanding of this dynamic relationship of how low-income and communities of color are unequally managed and protected in daily environmental conditions and extreme events.

In the two empirical papers, “Waterproof” and “Pavement and Prosperity”, multivariate and spatial regression are used to model two infrastructure datasets across 1,300 Census block groups in the City of Houston, Texas. The dataset in the first empirical paper, “Waterproof”, is an inventory for roadside open ditches and the dataset in the second empirical paper, “Pavement and Prosperity”, is from a city-wide pavement condition assessment. In “Waterproof”, communities of color are found to more likely to live in neighborhoods with open ditches and have a greater proportion of their roadsides equipped with open ditch systems; with race being the strongest predictor of the proportion of roadside open ditches controlling for median household income, population density, neighborhood age, housing improvement values, and vacant homes. Implications suggest several neighborhood factors are linked to the prevalence of these open ditch systems yet minority neighborhoods are particularly overburdened and under protected by these systems. Open ditches are particularly limited in discharging stormwater to protect people and mitigate the inundation of property, especially in urbanized areas. Communities of color may not have had the opportunity to have more fitting and alternative systems installed or their stormwater infrastructure systems retrofitted or replaced. Likewise, results suggest that outcomes like urban flood exposure might be greater in communities of color due to the greater amount of open ditch systems existing in these neighborhoods. These findings reveal opportunities for the installation of alternative, more fitting and current development systems or the retrofitting and replacement of these open ditch systems to green infrastructure or low-impact development standards.

The findings from "Pavement and Prosperity" show that there is spatial dependency across neighborhoods, both between neighbors and in the error term. Implications suggests the necessity of spatial models to avoid biased estimations and errors in hypothesis testing due to the interconnected nature of infrastructure systems. More importantly, the findings show that roadway condition is low for most communities. Contrary to what was hypothesized, communities of color are found to have marginally better condition ratings relative to the rest of the dataset, nevertheless these values are still low in terms of acceptable pavement and roadway condition. This study suggests that transportation infrastructure maintenance and rehabilitation needs are great across all communities. Collectively, this research shows the need for a continued environmental justice research agenda that addresses the planning, management, provision and distribution of infrastructure systems to improve neighborhood wellbeing and urban utility for communities across the country, especially communities of color.

CHAPTER II

UNEQUAL PROTECTION REVISITED: PLANNING FOR HAZARD VULNERABILITY, ENVIRONMENTAL JUSTICE, & CRITICAL INFRASTRUCTURE IN COMMUNITIES OF COLOR

Summary

This paper reviews key literature, examines conceptual frameworks, and raises issues around critical infrastructure that are not adequately addressed by existing hazard vulnerability and environmental justice literatures. This review shows how fundamental principles of Environmental Justice can bolster and compliment those of Social Vulnerability. The discussion and conceptual framework provide in-depth insight to how neighborhoods are not inherently vulnerable and that individuals do not prefer to live in environmentally unjust communities. There are certain social processes and larger planning and development patterns shaped by power and privilege that create pockets of disadvantage and prosperity. These same forces led to early racial zoning and later segregation and isolation of minority racial groups that resulted in deflated tax bases and built environments in disrepair. The rationale for this review is that environmental prosperity or demise is a direct result of social vulnerability in terms of neighborhood race, ethnicity, and class and the built environment is the physical manifestation of social circumstances that have been alluded to in both the disaster and environmental justice literatures.

Physical and engineered settings have to be explored with a progressive lens that views built features as a continuation of social circumstances for a comprehensive and robust understanding of this dynamic relationship of how low-income and communities of color are unequally managed and protected in daily environmental conditions and extreme events.

Keywords

Environmental justice, social justice, social vulnerability, infrastructure, built environment

Introduction

Over twenty years have passed since Dr. Robert D. Bullard (1994) wrote his profound anthology on environmental racism and injustice across America, discussing everything from the development of minority neighborhoods on SuperFund sites to the disproportionate burden of petrochemical facilities in communities of color. As one of the most recognized scholars in the environmental justice (EJ) movement, Bullard's collection of work draws associations between communities of color and environmental burden through case studies from around the country and set the stage for the next two decades of environmental justice scholarship.

In light of growing inequalities, urban revitalization, climate change, natural hazards and decaying critical infrastructure, the EJ agenda has to expand its horizon to include this new suite of environmental issues. Historically, the EJ agenda has primarily focused on traditional issues such as the siting of toxic and waste treatment facilities.

This paper pushes the science to include both well publicized toxic contamination issues and more invisible environmental problems that threaten the built environment and public safety, including public infrastructure. These latent environmental and built environment issues are not as noticeable as chemical facilities or landfills because they are built norms for communities of color and most often are inherited due to social forces that we live by every day. Likewise, these issues do not necessarily pose any adverse direct effects, but usually are threats that occur later, irregularly and overtime. Specifically, this paper describes how to conceptualize the role of infrastructure (such as stormwater infrastructure, transportation, sewers, etc.) as a mechanism that furthers environmental injustice and disparate impacts across population groups during everyday services as well as in mitigating the negative outcomes of environmental extremes.

To place infrastructure within this discussion of inequality, I incorporate the literature on social vulnerability to disasters with that of environmental justice. The social vulnerability literature is an extension of the traditional hazard vulnerability literature that narrowly focused on risk and physical vulnerability in terms of geographic location and proximity to a hazard. Social vulnerability is an improvement on that long-standing literature and provides an opportunity to focus on disparate exposure, impact, damage, and recovery outcomes from natural hazards for certain population groups. More specifically, the social vulnerability approach describes how social stratification based on race, income, disability, gender, age, nationality, among others contributes to differential risks and impacts from disasters. And more recently, some scholars (Van Zandt et al 2014; Cutter, Boruff, & Shirley, 2003) have begun to question the built environment and spaces that these marginalized groups occupy and how these physical features contribute to disparate impacts. The EJ literature has focused on similar disparities but among man-made environmental hazards and toxic facilities. This paper tackles the rich opportunity to create a framework that merges these two literatures to address growing environmental issues, with a focus on the role of planning and infrastructure in producing and maintaining unequal environmental and disaster outcomes for marginalized population groups. Furthermore, this work builds on the ideas that Cutter (1995) and Bolin (2007) first alluded to in how EJ applied to hazards research in general illuminates the value in tracing the development of the urban hazardscapes and comparative analyses of neighborhoods facing the greatest risks with those who are able to avoid them through zoning and land-use controls, housing deeds, and capital improvements, among others.

This paper begins with key literature in EJ and social vulnerability to highlight issues that are not adequately addressed and show how fundamental principles of EJ can complement and bolster those of social vulnerability to disaster. To ground this discussion in urban planning thought, larger planning and development patterns are discussed that include specifically social forces like racial zoning, residential segregation, discriminatory planning and neighborhood disinvestment to provide in-depth insight to how the black urban experience has shaped the circumstances for vulnerable communities of color. This background provides the foundation for the argument that critical infrastructure (i.e. physical safety-nets and lifelines) and the built environment are the physical manifestation of social circumstances (e.g. race, socioeconomics, culture, education, and politics), and complicit in generating the observed disparities across environmental and disaster outcomes. Critical infrastructure as a mechanism of generating environmental protection or exacerbating hazards is the new nexus for hazard vulnerability and environmental justice. Therefore, these physical issues have to be explored with a progressive lens that views built features as a continuation of social circumstances for a comprehensive and robust understanding of how low-income and communities of color are unequally protected from natural hazards and environmental threats.

Literature Review

Environmental Justice

"The nation's environmental laws, regulations, and policies have not been applied fairly across all segments of the population. Some individuals, groups, and communities receive less protection than others because of their geographic location, race, and economic status" (Bullard, 1994: XV). These words describe the unequal protection of communities of color and are the central premise of environmental justice research and activism. The environmental justice framework focuses primarily on uncovering the underlying assumptions that may influence environmental decision-making and how these decisions result in disparate outcomes across population groups. It also rests on an analysis of strategies to eliminate unfair, unjust, and inequitable conditions and decisions. The environmental justice framework more precisely, brings to surface the ethical and political questions of who gets what, why, and in what amount (Bullard & Lewis, 1996). The principle of environmental justice guarantees 1) the protection from environmental degradation; 2) prevention of adverse health impacts from deteriorating environmental conditions before the harm occurs, not afterwards; 3) mechanisms for assigning culpability and shifting the burden of proof of contamination to polluters not residents; and 4) redressing the impacts with targeted remedial action and resources (Cutter, 1995).

Environmental activism and the systematic study of environmental circumstances especially for communities of color are not new. In fact, some of the early work of W.E.B DuBois, specifically in *The Philadelphia Negro* (1899), is an example of some of the earliest of works that studied the black community and used mixed-methods research to document the social environment that blacks in American cities, Philadelphia precisely, inhabited during and following the reconstruction era. This was the first scholarly race study of urban life for Black Americans and catalyzed the trend for social surveys and case studies using both quantitative and qualitative methods to demonstrate inequities in the Black urban experience through the examination of housing, health, poverty, employment, and education , among others. DuBois' work was the first to show that Blacks in American cities were much more likely in comparison to Whites to suffer from or experience illiteracy, unemployment, unlivable wages, higher death rates, alcoholism, and unsanitary and unsafe living conditions.

However, environmental justice scholarship and the modern movement by the same name, by most accounts point to the protests of 1982 in Warren County, North Carolina as the beginning of the environmental justice movement. The protests began when a site (Afton) in Warren County was selected by the state to host a hazardous waste landfill to dumb over 6,000 truckloads of 30,000 cubic yards of polychlorinated biphenyl (PCB)-contaminated soil in what was a predominately Black, rural, and poor area (Bullard, 1990; 2000; Bullard, 1994; Cutter, 1995; Taylor, 2011). PCBs are members of the family of halogenated aromatic hydrocarbons, some of the most toxic substances known to life (Bullard, 1994). Even in small amounts, it has been documented that PCBs can cause severe rashes, accompanied by discharge from the eyes, hyperpigmentation of the skin and nails, headaches and physical weakness. The publication of two studies surrounding this incident, one by the United States General Accounting Office (USGAO, 1983) and the other by the United Church of Christ's Commission for Racial Justice (1987), incited the movement and provided empirical evidence for the claims of environmental racism (Cutter, 1995). Robert Bullard's, *Dumping in Dixie* (1990) contributed to the empirical support for the disproportionate burden of toxic waste on communities of color and is the text that essentially landed him the title of the "Father of the Environmental Justice Movement." Following these publications between 1990 and 1992, several conferences and summits on race and environmental hazards were held and some notable entities and legislation were introduced including the United States Environmental Protection Agency (USEPA, 1992a) Office of Environmental Equity, the Environmental Justice Act of 1992, and President Clinton's Executive Order 12898 – a federal mandate to address environmental justice in minority populations and low-income communities.

The Warren County PCBs protest failed to prevent the landfill from being completed, but it succeeded in a number of ways including (1) the governor, James

Hunt, initially refused to meet with the group but was later forced to make concessions to the community, (2) there were no more landfills built in Warren County and well water and body levels were monitored, and (3) the Concerned Citizens Group that was behind a lot of the protesting 15 years later were still actively pressuring the state to remove or remediate the landfill site (Bullard & Lewis, 1996). In the grand scheme of things, the Warren County protests illustrated some of the real opportunities for the intersection of empirical scholarly work, community engagement, and citizen action.

Since that time, hundreds of studies have documented unequal exposures by race, ethnicity, and economic class regarding well-publicized issues such as waste and petrochemical facility siting (Hernandez, Collins & Grineski, 2015) to more hidden issues in environmental injustice including the distribution of urban trees (Landry & Chakraborty, 2009), liquor stores and bars (Romley, Cohen, Ringel, & Sturm, 2007), and urban green space and parks (Wolch Byrne & Newell, 2014; Boone et al, 2009), among others. More specifically, amongst the more obvious and well-publicized environmental issues researchers have provided evidence of the disproportionate siting of hazardous facilities in low-income and communities of color (Bullard, 1983, 1990; USGAO, 1983; Mohai & Bryant, 1992) and disparities in exposure to pollutants (Mohai & Bryant, 1992). Bullard's work in 1983 examined the siting patterns of waste dumps in the city of Houston and found that these sites were not randomly distributed across Houston. These sites were located in predominately Black communities and near schools with four of five of the city's incinerators being located in predominately Black neighborhoods and the fifth was found in a predominately Hispanic neighborhood. Bullard also found that five of Houston's six municipal landfills were located in predominately Black neighborhoods. In 1991, K. Brown found that toxic-waste emitting facilities were disproportionately located in Black communities in St. Louis. Mohai and Bryant (1992) examined racial disparities in proximity to commercial hazardous waste facilities in Detroit and found that minorities were more likely than Whites to live in close proximity to such facilities.

More recently, a report from 2007 produced by Bullard and his colleagues show that people of color make up the majority of those living in host neighborhoods within 3 kilometers (1.8 miles) of the nation's hazardous waste facilities. Furthermore, more than 5.1 million people of color, including 2.5 million Hispanics or Latinos, 1.8 million African Americans, 616,000 Asians/Pacific Islanders and 62,000 Native Americans live in neighborhoods with one or more commercial hazardous waste facilities. At the neighborhood level with clustered facilities close together, have higher percentages of people of color. Mohai and Saha (2007) found that disparities exist even when controlling for economic and sociopolitical variables, suggesting that factors uniquely associated with race, such as racial zoning/targeting, housing discrimination, or other race related social and planning forces are associated with the siting of the nation's hazardous waste facilities. Likewise, a study done by Manuel Pastor, Jr. and some of his colleagues in 2004 suggests that a pattern of disproportionate exposure based on race, with the disparity most severe for Latinos, controlling for spatial dependence exists in 21st-Century California. Racial and ethnic environmental disparities are prevalent throughout the country.

Despite controversy over the assertion that race and class are related to the siting patterns of hazardous facilities, most studies support the claim (Taylor, 2011). The contended issue and controversy is with the “chicken-or-egg” question: Which came first, the hazardous facilities or the people? That is, some argue that industrial and waste disposal facilities were established first and then minorities and low-income people constructed residences around them because the land was cheap or because jobs were available (Taylor, 2011). Other scholars rebut that assertion and argue instead that hazardous facilities are passively and deliberately placed in minority communities. Several case studies from around the country provide examples that minorities resided in communities selected to host hazardous facilities before the facilities were built (Taylor, 2014). Black communities all across the south specifically provide examples in which landfills were placed in Black communities. Beyond the south, studies examining communities in South Central Los Angeles (California) and in Pennsylvania have shown that Blacks and Hispanics lived in neighborhoods before incinerators were placed in them (Pardo, 1998; Cole & Foster, 2001). Another study done by Saha and Mohai (2005) showed that patterns beginning in the 1970s of placement of waste facilities in communities of color grew out of hazardous waste facilities attempting to avoid political resistance from public environmental concern thus resulted in disproportionate siting of these facilities in communities of color, whom had little if any political influence. They found race-based sitings to be significant after 1970. Furthermore, work done by Downey in 2005 showed that the distribution of these polluting manufacturing facilities is largely the product of residential segregation. In either scenario, chicken or egg, the nation's environmental laws and regulations have failed to protect communities of color.

Additionally, there is even a growing body of work in environmental justice that shows how climate change, disasters, and critical infrastructure create unequal impacts on communities of color, indigenous peoples, the poor, and developing countries (Mohai, Pellow, & Roberts, 2009). As for climate change issues, climate justice work is beginning to discuss how marginalized groups such communities of color, indigenous groups, the geographically isolated, and low-income communities are already experiencing hardships when it comes to the ability to respond and adapt to climate change (Gutierrez & LePrevost, 2016). Other works in climate justice and vulnerability specifically show how the geographically isolated, low-income and elderly are at greater risks of heat wave impacts and may not have adequate heating or cooling leading to early deaths as seen in the 1995 Chicago Heat Wave (Cutter et al., 2014; Klinenberg, 2003). An example of when environmental justice and disaster outcomes begin to interact in the case of communities of color in New Orleans during and following Hurricane Katrina. In the work of Bullard and Wright (2009) they pointed out that in May of 2008 following Hurricane Katrina, Black storm victims were more than twice as likely as white storm victims to still be living in temporary housing. Likewise, they showed that neighborhoods that were in the range of 75 to 100 percent Black at the time of Census 2000 were flooded. Beverly Wright's independent work (2011) goes on to show that changes in levee protection were closely related to the racial composition of neighborhoods. In fact, in the mostly white and affluent areas, in contrast to the Black and working class areas, there was 5.5 feet of increased levee protection.

Lastly, as of 2016 work explicitly discussing critical infrastructure has emerged in the context of environmental justice and the delivery of clean water in Flint, Michigan. Butler, Scammell, and Benson (2016) show that many of the affected residents from the water crisis are living in economically depressed areas with high rates of racial minorities. Greenberg (2016) goes on to illuminate that Flint fits the pattern of poor living in many physically distressed neighborhoods. Such urban neighborhoods typically have relatively high burdens of environmental deterioration that includes water and other infrastructure systems, public problems such as crime and physical blight, poor public education systems, and a limited tax base. Continued focus on environmental justice communities and the cumulative risks faced by their residents is critical to protecting these residents and, ultimately, moving towards a more equitable distribution and acceptable level of risk throughout society (Prochaska et al, 2014).

This discussion of disaster impacts, vulnerability, and infrastructure provides a bridge between traditional EJ research and disaster scholarship that focuses on social vulnerability. The hazard and disaster literature also developed a discussion of social stratification and disparate impacts from natural hazards, but this literature is mostly disconnected from the body of work on EJ. Likewise, the EJ work that explores instances of disaster and vulnerability are underdeveloped. Understanding the two together is necessary to address questions about infrastructure and planning for equitable communities across complex environmental problems of the future.

Hazard Vulnerability

Vulnerability has been defined and conceptualized in many ways over the years as both one dimension of other concepts such as, resiliency and sustainability, and also as a standalone area of rigorous study. The concept of vulnerability has also been used as a blanket term for understanding susceptibility to risks as well as defined with more specificity to include discussion of natural and environmental hazards (Adger, 2006). The international and global view of vulnerability as stated by the United Nations Development Programme (2004, p. 11) define it as "… a human condition or process resulting from physical, social, economic, and environmental factors, which determine the likelihood and scale of damage from the impact of a given hazard." However, in this review I want to focus on defining vulnerability through the lens of natural hazards research, specifically in the United States.

In general, the measurement of vulnerability must account for social dynamics as well as the physical dimensions within systems that are multifaceted (Wisner et al, 2004; Cutter, Boruff, & Shirley, 2003; Morrow, 1999; Phillips, Thomas, Fothergill, & Blinn-Pike, 2010; Peacock, Morrow, & Gladwin, 1997; Fothergill & Peek, 2004; Adger, 2006; Van Zandt et al, 2012). There are two main types of vulnerability: physical and social. Physical vulnerability is defined by the role of place and proximity in shaping risks and hazard exposures (Brody, Zahran, & Grover, 2008). As for the term "social vulnerability", which is an extension of physical vulnerability, as defined by Blaikie and his colleagues (1994) is ubiquitously accepted as the most practical articulation of the concept across the hazards literature. Blaikie and his colleagues (1994, p. 9) define social vulnerability as "… the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard."

Physical Vulnerability

Physical vulnerability in a natural hazards context is usually characterized by physical (e.g., environmental) conditions like location and proximity to a hazardous threat (Brody, Zahran, & Grover, 2008; Douglas, 2007; Uzielli et al., 2008). Brody, Zahran, and Grover (2008, p.89) describe physical vulnerability as: "Living adjacent to the coastline and/or areas of low elevation presents obvious threats from hazards. Thus, physical position and proximity characteristics lend themselves to increased potential negative hazard exposure impacts." Several studies have tested the effects and explanatory power of physical vulnerability variables such as storm shutters, location to floodplains, building codes, and mitigation policies on predicting flood exposure (Cutter & Emrich, 2006), individual risk perceptions (Brody, Zahran, & Grover, 2008), damage amounts, flood claim data, and climate change impacts (Adger, 1999). These studies have generally found that these "physical" attributes do have some explanatory power, but do not wholly account for variation the effects of disaster across population groups. Furthermore, physical vulnerability is poorly modeled for several reasons, (1) the difficulty in parsing out the cause of casualties during disaster events and them being a result of the hazard alone or some other physical dynamic that might have exacerbated impacts, (2) lack of observational data on the hazard over time and when certain mechanisms allow that hazard to evolve into an emergency or disaster, (3) the complexity of built environment circumstances, and (4) the temporal and spatial scales even within the same relative geographic location and the ability to modify the hazard level (Van Zandt et al, 2012; Douglas, 2007). Most of these issues and uncertainties can be better explained by including variables related to social vulnerability.

Social Vulnerability

Social vulnerability goes beyond physical risk and takes into consideration individual and community socioeconomic characteristics, capacities, culture, education, and politics that impact the abilities to anticipate, respond, cope, and recover from hazardous events (Wisner et al, 2004; Cutter, Boruff, & Shirley, 2003; Morrow, 1999; Phillips et al., 2010; Tierney, 2006; Peacock, Morrow, & Gladwin, 1997; Fothergill & Peek, 2004; Van Zandt et al, 2012). Social vulnerability is drawn from literature on social inequalities and macrosocial ideologies, such as racism, classism, and sexism, that effect various groups' likelihood of exposure and ability to resist disaster impacts (Cutter, Boruff, & Shirley, 2003; Bolin, 2007). This perspective is based off of numerous studies following disasters that show even with similar physical risk, such as living in a floodplain, certain population groups are more likely to be injured or killed, have higher damage rates, and slower recovery rates.

In general, age, gender, race, and socioeconomic status are the most common proxy variables that allow us to estimate social vulnerability (Cutter, Boruff, & Shirley, 2003). But scholars use numerous different indicators of population variation to help explain social vulnerability and variance in disaster effects. For example, Cutter et al. (2003, p. 243) state that social vulnerability includes place inequalities, which are “characteristics of communities and the built environment, such as the level of urbanization, growth rates, and economic vitality.” Cutter et al. (2003) provides the Social Vulnerability Index, which has become a prominent model in the field. This Index includes indicators of: socioeconomic status, gender, race and ethnicity, age, commercial and industrial development, employment loss, rural/urban, residential property, infrastructure and lifelines, renters, occupation, family structure, education, population growth, medical services, social dependence, and special needs populations. Other scholars include and focus on persons with special needs or disabilities, persons who speak a language other than the native language of the area, and homeless (Cutter et al., 2003). Flanagan et al. (2011) uses four domains to form the basis of the Social Vulnerability Index (SVI) including socioeconomic status, household composition and disability, minority status and language, and housing and transportation, whereas Van Zandt et al. (2012) recognizes race/ethnicity, income and poverty, and gender, as well as other factors such as age, education, religion, social isolation, and housing tenure as potential indicators social vulnerability.

General and key findings in the social vulnerability literature include contributions from a community of scholars that have advanced this work. Lori Peek (2008) found that as the frequency and intensity of disaster events increase around the globe, children are among those most at risk for the negative effects of disaster. Children have special needs and may require different forms of physical, social, mental, and emotional support than adults. Similarly, Brenda Phillips and colleagues (2010) discussed how following Hurricane Katrina, over 160,000 children from Louisiana and

Mississippi were displaced from their homes and schools, and this population has subsequently suffered from high rates of emotional and behavioral problems, chronic health conditions, and poor access to medical care. Work by Patrick Sharkey (2007) determined that another vulnerable group in Hurricane Katrina were the elderly. He concluded that old age was the single most important factor in determining who died in New Orleans, 67% were at least 65 years old, although this group only represented about 12% of the pre-storm population. Connecting both children and the elderly, in the 1995 Kobe earthquake, 53% of the fatalities were among older persons and 10% of the victims were children (Hewitt, 2007). The experience of the women of New Orleans and the Gulf Coast at the time of both Hurricane Katrina and Rita were that female-headed families in the Gulf Coast region faced very high poverty rates. Nearly two in every five female-headed families with children in New Orleans, both the city and metropolitan area, lived in poverty in 2004, making these groups generally more vulnerable (Gault et al., 2005). These experiences were not new or unique to New Orleans and Hurricane Katrina because work done by Betty Morrow and Elaine Enarson (1996) related to Hurricane Andrew nearly ten years earlier found that being female was an important dimension which appeared to increase the negative effects of being a victim and to slow personal and family recovery.

The examination and discussion of the historical and cultural complexities of race and ethnicity in the disaster literature is limited (Bolin, 2007). Perhaps because of the complexities inherent in disaster research itself. There is a tendency to rely most often on surface level indicators and proxies for the more substantive issues. To get after the ideologies of racism and discrimination, it requires a deeper review of the literature or more qualitative methods. Early on work done by Walt Peacock, Betty Morrow, and Hugh Gladwin (1997, 2001) challenge these limitations and provide an empirically richer, more contextualized understanding of race and ethnicity following Hurricane Andrew. Peacock et al. (1997) found that neighborhoods that are already socially vulnerable or at considerable risk are further marginalized through negative social and environmental outcomes following disasters. They reference that disaster event marginalization is not a result of a single event or the disaster agent itself, but rather a series of obstacles built into the urban social structure that places certain neighborhoods and households at substantially higher risk. This notion runs parallel with implications from the environmental justice literature. Finally, Peacock, Morrow, and Gladwin discuss how the effect of living in segregated Black neighborhoods is consistently significant in disaster impacts, regardless of which variables are added to the models. Another example of classic work related to race and disasters explored in Moore's *Tornadoes Over Texas* (1958) found that Blacks had disproportionate losses from a tornado and consequently had greater need for external assistance to recover. Moore also found that Blacks had a higher injury rate than whites. Bates and colleagues (1963) found that mortality was significantly higher among Blacks than among Whites following Hurricane Audrey. Bolin and Bolton (1986) researched different hazard types across different states. They found racial disparities in temporary housing and aid provision, with Blacks more likely to live in mobile homes provided by the federal government and also less likely to obtain adequate aid for their recovery needs from both house insurance and from the federal government than were whites. Bolton, Liebow, and Olson (1993), showed that low-income Latinos were most housed in unstable unreinforced masonry buildings before an earthquake and then coped with housing damage and displacement afterwards.

More recently and more specifically related to race and class, Fothergill and Peek (2004) and Masozera, Bailey, and Kerchner (2007), express that socio-economic status is a significant predictor for the likelihood of exposure and impacts and is strongly correlated with race relations and social structures that moderate power and capacities. The literature on poverty and disasters illustrates that the impoverished in the United States are more vulnerable to natural disasters due to such factors as place and type of residence, building construction, and social exclusion. Low-income populations may be differentially impacted, both physically and psychologically, and disaster effects vary by social class during the periods of emergency response, recovery, and reconstruction (Fothergill, 2012; Phillips, 2010; Vaughan, 1995). Similar work by Masozera, Bailey, and Kerchner (2007) found during a case study of New Orleans that pre-existing socio-economic conditions played a significant role in the ability for different income groups to respond to and cope with impacts in the outcome of Hurricane Katrina.

However, it is imperative that we do not discount issues of race and ethnicity in the context of social vulnerability (Bolin, 2007), just as we cannot discount race in issues of environmental justice. Issues of race and ethnicity paint a vivid picture of increased vulnerability and risk to disasters for communities of color across the US. For example, while in many ways class cannot be separated from issues of economic resources and power, race explains marginalization in the disaster experience in a way that socioeconomic factors cannot (Fothergill, Maestas, & Darlington, 1999). Shannon Van Zandt and some of her colleagues (2012) in discussing housing damage and recovery show that neighborhoods with higher proportions of racial minorities are less likely to have begun undertaking significant repairs in the recovery phase of disaster. Other work by Highfield, Peacock, and including Van Zandt (2014) show that even after controlling for a variety of spatial and structural characteristics, homes located in areas with higher proportions of both Hispanic and Blacks were found to have experienced more damage following Hurricane Ike. Their work also shows that equations that include the proportion of whites, rather than minority proportions, the effect was negative and statistically significant, providing additional evidence that housing in minority neighborhoods were disproportionately impacted with higher levels of damage compared to white areas, after controlling for physical and structural vulnerability. These findings indicate an independent effect for minority status and lower incomes. While additional research is needed, suspicions that greater damage stems from disinvestment in the community—poorer upkeep, a lack of infrastructure, and regular maintenance, etc.—are warranted. The causes of disinvestment in poor, minority neighborhoods are complex, but the finding that greater damage may be a consequence adds to the evidence that both mitigation and recovery resources should be prioritized in areas where they can have the greatest impact.

Research incorporating the historical geographic context related to race and class, especially patterns of segregation, provides the next step to further this body of research.

Environmental justice research and vulnerability studies both offer fertile ground to develop the theoretical and methodological tools and address this need and planners specifically have the conceptual baseline to address issues of zoning, disinvestment, spatial exclusion, and segregation. To fully understand how planning, and the historical legacy of planning policies, affect disparate impacts especially for blacks, we must situate this discussion within the black urban experiences of racial zoning, segregation and disinvestment.

Neighborhood Factors and Inequalities in the Distribution of Infrastructure Systems

There are certain social processes and larger planning and development patterns shaped by power and privilege that create pockets of disadvantage and prosperity. These same forces have led to early racial zoning and later segregation and isolation of minority racial groups that resulted in deflated tax bases, built environments in disrepair, the siting of toxic facilities, and disproportionate disaster impacts. These are the very issues behind the concepts of environmental justice and social vulnerability discussed above.

The social forces that have led to unequal development in a historical sense include Jim Crow laws, racial zoning, and laws prohibiting racial intermingling (Hoelscher, 2003; Silver, 1997). Following the outlawing of race-based zoning, the social and planning forces include private deed restrictions, covenants, or building ordinances (Berry, 2001), urban sprawl (Le Goix, 2005), street and highway planning that have been used as physical mechanisms to separate neighborhoods (Connerly, 2002), the siting of public and affordable housing (Massey & Kanaiaupuni, 1993), municipal underboubding (Marsh, Parnell, & Joyner, 2010; Squires & Kubrin 2005), and homeownership (Van Zandt, 2007) and home buying discrimination (Seitles, 1998; Silver, 1997). All these social and planning forces impact uneven development and are underlying mechanisms that inform urban development and some of them predate contemporary zoning and have persisted as land-use controls in some places to maintain invisible racial zoning and pockets of racial disadvantage.

Berry (2001) shows that zoning may be one of the primary causes of residential segregation in cities that use it, but there are other methods of land use control that can produce similar results in the absence of zoning. More specifically, deed restrictions achieve in Houston for example what zoning might elsewhere. They empirically compared Houston (no formal zoning) and Dallas (formal zoning) two otherwise similar Metropolitan Statistical Areas (MSA), and found remarkable similarity between Houston and Dallas at every level in segregation within a 95% confidence level suggesting that they are statistically indistinguishable. Deed restrictions can be directly tied to urban sprawl and the creation of new developments, suburban develops and gated communities. Le Goix (2005) concluded that sprawl increases segregation. He found very significant socio-economic dissimilarities and these are associated with enclosure thus defining very homogenous areas. He also found that gated communities particularly are located in ethnic buffer zones that stress exclusion at the municipal level. When it comes to highway mechanisms of exclusion and isolation, Connerly (2002) shows how the construction of interstate highways through black neighborhoods in the city have led to significant population loss in those neighborhoods and is associated with an increase in neighborhood turnover. Public housing is another structure that has both social and physical connotations and implications that lead to segregation. Massey and Kanaiaupuni (1993) exposed that public housing projects were targeted to poor and black neighborhoods and the presence of housing projects has substantially increased the concentration of poverty over the years. Municipal underbounding (the unwillingness of cities to annex poor neighboring areas) and the manipulation of municipal boundaries is another mechanism that creates local apartheids, exclude communities of color and keep these neighborhoods on the outside with no political voice and no investment, restricting their opportunities to gain necessary services and critical infrastructure (Marsh, Parnell, & Joyner, 2010; Squires & Kubrin 2005). Lastly, Van Zandt (2007) brings attention to the idea that homeownership may lead to poorer neighborhood conditions for all lower-income buyers and that appears to exacerbate and generally contribute to social and spatial isolation.

Residential Segregation

Residential segregation in the United States is the physical separation of two or more groups into different neighborhoods, or a form of segregation that sorts population groups into various neighborhood contexts and shapes the living environment at the neighborhood level. Residential segregation can be a result of race or class or the interaction of both race and class (Massey & Denton, 1993; 1988). Because there is usually such a strong correlation between these two types of segregation, segregation by means of one will simultaneously result in segregation of the other. For example, roughly 30 percent of America's poor reside in poor places, and spatially clustered poverty is especially high among poor African Americans (Lichter, Parisi, & Taquino, 2012). According to Litcher and colleagues (2015) the macro component of segregation or between place components is also most pronounced and increasing most rapidly among Blacks, accounting for roughly one-half of all metro segregation in the most segregated metropolitan areas of the United States.

This significant increase of segregation has transformed into the concept of hypersegregation, first developed by Massey and Denton (1988) to describe metropolitan areas in which African Americans were highly segregated on at least four of the five dimensions of segregation they had identified in an earlier analysis including unevenness/evenness (e.g. the differential distribution of two social groups among areal units in a city), exposure (e.g. the degree of potential contact, or the possibility of interaction, between minority and majority group members within geographic areas), clustering (e.g. the extent to which areal units inhabited by minority members cluster in space), concentration (e.g. the relative amount of physical space occupied by a minority group in the urban environment), and centralization (e.g. the degree to which a group is spatially located near the center of an urban area) (Massey & Denton, 1988). Over the period from 1970 to 2010, 52 metropolitan areas satisfied the criteria for black hypersegregation at one point or another (Massey & Tannen, 2015). Amongst these metropolitan areas are Baltimore, MD, Chicago, IL, Flint, MI, Houston, TX, Philadelphia, PA, St. Louis, MO, New York, NY and Washington, D.C., among others. Among all African Americans living in the United States in 1970, nearly one-half (47 %)

lived in a hypersegregated metropolitan area compared to 26 % by 2010 (data on total black populations come from the decennial census). Likewise, among black metropolitan residents, 61 % were hypersegregated in 1970 compared with 32 % in 2010 (Massey & Tannen, 2015).

Racial segregation in central and rapidly growing cities means greater concentrated poverty and fewer opportunities for economic mobility. For example, 94 percent of D.C. neighborhoods with a majority white population have less than 10 percent of their families living below the poverty line, compared with 22 percent of majority Black neighborhoods (Butler & Grabinsky, 2015). Likewise, just 4 percent of predominantly white neighborhoods have 30 percent or more of their families living below the poverty line, compared with 38 percent of predominantly black neighborhoods. The collective, cumulative, and continuing legacy of the racialization of space in the United States today makes itself felt most powerfully within black communities in the form of structured disadvantages revolving around environmental politics of place (Lipsitz, 2007). Shapiro (2004) shows that between 1990 and 2020, some seven to nine trillion dollars will be inherited by the baby boom generation. Almost all of that money is rooted in gains made by whites from overtly discriminatory housing markets before 1968. Place has been the subject of much of the analysis related to racial disparities that have been both driven by, and reflected in, geographic differences with regard to access to employment, schools, and opportunity (Pastor, 2001). Race likewise remains an independent factor—careful research by Kirschenman and Neckerman (1991) and Kirschenman et al. (1996) indicates that developers and employers still exhibit preferences to hire nonminorities and develop in areas of the same makeup, with special discrimination faced by Blacks. For example, local city governments and private development firms have been more likely to cut spending and services in poor neighborhoods, areas that lack political power, and communities of color, than in more affluent areas (Williams & Collins, 2001).

The preferences and privileges of Whites in America have mostly shaped what we have come to recognize as residential segregation. According to Emerson, Chai, and Yancey (2001) at very low percentages of Blacks in the neighborhood and, controlling for other variables that serve as proxies for race, whites state that they are likely to buy a house. In the range of 10 to 15 percent black, whites state that they are neutral about the likelihood of buying the house. Furthermore, they conclude that above 15 percent Black, Whites are unlikely to buy a house. The strength of this stated unlikeliness increases with increases in the percent Black. Their findings suggest a low probability of whites moving to neighborhoods with anything but a token Black population, even after controlling for the reasons they typically give for avoiding residing with African Americans. The preferences of Whites are but one factor shaping residential segregation by race, but nevertheless is a powerful factor.

Privileges in urban-dwelling usually manifest, between the public and private realm, through urban revitalization, urban design and aesthetics, which usually fail to consider social equity and justice. Therefore, when planning approaches and urban designs such as new urbanism, sustainable development, mixed-use, traffic-calming, low-impact development, complete streets and smart growth etc. fail to account for social stratification, the discipline as a result is maintaining patterns of segregation and fragmentation in cities. This is a similar occurrence as during the phenomenons of suburbanization and urban renewal, particularly with segregated communities of color getting the short end of the stick (Wilson, Hutson, & Mujahid, 2008). Privileged and costly urban design and policy approved by planning officials and funded by private actors is another powerful factor in determining segregation. Equity and environmental justice-based policy decisions could be made to alter this pattern of development (Squires & Kubrin, 2005). The urban experience of residential segregation for marginalized groups are largely shaped by preferences and privileges —both of which play out in large part from the intersection of public policy decisions and practices of powerful private actors and institutions.

Neighborhood Disinvestment

Blacks, specifically, live under unbecoming conditions where they are targeted for environmental inequalities, the infrastructure is inadequate, and built environments are in disrepair and therefore are subjected to disinvestment (Massey & Denton, 1993). More precisely, by way of segregation, Blacks in the city often find themselves at-risk and in segregated communities characterized by dilapidated housing stock, stifled growth, and marginal tax bases—drivers for public services, community development and capital improvement (Orfield, 2005; Sandler & Pezzullo, 2007; Bolin, 2007). Residential segregation has shaped the differences in neighborhood quality for Blacks and has concentrated poverty, crime, and a bevy of health disparities as a result of food deserts, substandard health care and environmental hazard exposure, which is starkly different from the experience of White groups living in affluent areas (Williams & Collins, 2001). For example, Kwate (2008) focuses in large part on New York City, but draws parallels in urban contexts for other large, racially segregated cities such as Chicago, Boston, and Washington, DC to argue that fast food may be dense in Black neighborhoods due to the downstream effects of segregation through four pathways: population characteristics, economic characteristics, physical infrastructure, and social processes. This work shows how segregation tends to create localized geographic areas for targeting of unbecoming development (e.g. fast food, liquor, tobacco, waste, and oil corporations and operators); fosters economic and business conditions and land use characteristics that increase the likelihood of unideal urban landscapes thereby concentrating community and economic disinvestment. Sampson and Raudenbush (2004) found that as the concentration of minority groups and poverty increases, residents of all races perceive heightened disorder even after accounting for an extensive array of personal characteristics and independently observed neighborhood conditions. These perceptions may be triggered by existing or forthcoming signs of physical decay and disinvestment. Furthermore neighborhood disinvestment, might have an impact on opportunities for residential achievement. Results from a study done by Massey and Fong (1990) found in light of residential segregation that blacks were disadvantaged in the process of residential achievement (i.e. higher property values, neighborhood amenities, employment opportunities, quality infrastructure).

Disinvestment in particular neighborhoods can also have consequences in times of disaster. The social vulnerability literature has alluded to how communities of color might experience greater damage because they live in more structurally vulnerable (i.e., poorer quality) homes in more physically vulnerable (e.g., lower-lying) areas. For example, the work by Highfield, Peacock, & Van Zandt (2014) show an independent effect for minority status and suggest that greater damage stems from disinvestment in the community (e.g. poorer upkeep, distressed infrastructure, and irregular maintenance), not just physical location or individual household economic attributes. The sociological work primarily focuses on household vulnerability, while Cutter's work measures household vulnerability at the county level for the purpose of describing it. But this work and the work of Van Zandt (2012; 2014) is conceptualizing the neighborhood level of vulnerability. Current social vulnerability literature assumes that individuals or households are stratified within society which lead them to live in different types of housing, have different resources to prepare/respond/recover to disaster, and have differential power to address their needs in disaster. But, this limited research takes the neighborhood, specifically neighborhood-level features such as infrastructure, that contribute to racial disparities scene at household level analyze. This is crucial because it mean that when Blacks with higher socioeconomic status are still segregated into neighborhoods with higher minority populations they will have greater disaster impacts than if they lived in predominately white areas. This is also crucial because it is clearly within the job description of planners to provide services equitably to all persons in their community.

Residential segregation and neighborhood investment or lack thereof impacts tax bases which are necessary to support capital improvement, environmental protection, and the management of critical infrastructure (Badger, 2013). There is a clear need for infrastructure improvements in our cities (Stein, 1988; Lemer, 1992), especially low-income and communities of color, but customary planning operations will not get us there. Too often, planners fail to consider the impact of tax bases and investment decisions on communities and how the physical, constructed and built environment have implications beyond aesthetics. It is the responsibility of planners and local government to correct that and provide basic services and public safety, period. The black urban experience (e.g. residential segregation and neighborhood disinvestment) has potential for explaining the variation in everyday racial and economic outcomes, disaster impacts, as well as environmental justice concerns. Yet, there is little to no research that clearly connect these paradigms. There especially is no research that links infrastructure provision with environmental inequalities. Assessment and the conceptualization of disparities in critical infrastructure rooted in the black urban experience provides a new way to understand this issue.

Critical Infrastructure: The New Nexus for Social Vulnerability and Environmental Justice

Critical infrastructure theory is vital to understanding social vulnerabilities and environmental injustices for the receipt of basic services and environmental protection at the neighborhood level. Disparities in provision and unequal protection can impact everyday prosperity and disaster resistance (Kappes, Papathoma-Köhle, & Keiler, 2012). Therefore, in the future development of the present methodologies of social vulnerability and environmental justice, data and analyses regarding the management (i.e. inventory, distribution, and condition) of critical infrastructures must be included.

The Role of Critical Infrastructure

Critical infrastructures consist of man-made systems that function to produce and distribute a continuous flow of essential services towards social welfare, such as energy, transportation, emergency services, and water systems, among others (Rinaldi, Peerenboom, & Kelly, 2001). Infrastructure has been defined in many ways; for example those physical systems and facilities that are sometimes called public works and are developed or acquired by public agencies to house governmental functions and provide water, power, waste disposal, transportation, and similar services to facilitate the achievement of common social and economic objectives (Hudson, Haas, & Uddin, 1997). Certain definitions of infrastructure only consider infrastructure to be a fixed asset of value to the government. This is a limited perspective and ignores the value of these assets to the citizen. Therefore a more progressive definition of infrastructure refers to all these combined facilities that provide essential services of transportation, utilities (water, gas, electric), energy, telecommunications, waste disposal, park lands and green space, recreation, and on occasion housing. Infrastructure also provides the physical systems used to provide other services to the public through economic and social actions, like public health and emergency services (Hudson, Haas, & Uddin, 1997). These infrastructure facilities and services are provided by both public agencies and private enterprises (Stein, 1988).

Infrastructure systems are fundamental public services that require integrated infrastructure systems and plans. These systems require effective care over their life cycle to produce good service and high return on assets. Infrastructure systems are increasingly connected and dependent on one another and these interactions can produce effects upon environments that are difficult to predict and have immediate and longstanding social ramifications (i.e., cascading social and physical vulnerabilities) (Zimmerman, 2001). Interdependency and interconnectedness as they apply to infrastructure systems generally speak to the idea that there is affinity between all systems. Although interdependency and interconnectedness are similar terms and often times used interchangeably, there is a nuanced conceptual difference between the two terms. The interdependency and interconnectedness of infrastructure systems are complex, but intuitive, yet not well understood systematically in terms of their connections to larger social and physical processes (Rinaldi, Peerenboom, & Kelly, 2001).

Interconnectedness refers to the connection of infrastructure systems with one another through a shared assemblage. Zimmerman (2001) describes interconnectedness as a formal linkage, usually by way of physically joining or fastening together, between two different systems. For example, infrastructure systems can interconnect upon expansion of an existing system (i.e. newer systems are introduced into older infrastructure networks). Certainly, power lines/grids are an interconnected demonstration in that a shock or disruption to one network might be felt by all others. One electrical circuit breaks or wires snap and the vibrations are felt throughout.

However, Zimmerman (2001, pg 100) also describes how infrastructure can be interconnected functionally and spatially. Zimmerman states, “Functionally, infrastructure systems can be dependent upon one another operationally, e.g., one system activates the other. Spatially, as infrastructure becomes more dense and compact and as distributed networks occupy the same conduits in cities, vulnerability to breakages can increase.”

Interdependency rises a level above just being connected to being operationally contingent and conditioned upon one another (Zimmerman, 2001). Interconnected assets are usually interdependent as well. Interdependence means that not only do infrastructural systems sense each others’ existence, but are dependent on one another. Rinaldi, Peerenboom, and Kelly (2001 pg:14) define infrastructure interdependency as “a bidirectional relationship between two infrastructures, through which the state of each infrastructure influences or is correlated to the state of the other infrastructure.” Furthermore, interdependencies are an intrinsic part of infrastructure design and can be a source of a much wider scale vulnerability or disruption than any single system. For example, in the event that communication systems are interrupted this directly impacts emergency services and its ability to be made aware of needed relief and effectively respond. Likewise, transportation systems (roads and bridges) are dependent on stormwater systems to drain off water so that they may function. Better understanding the impacts and vulnerabilities of infrastructure systems through interconnectedness and interdependencies will be a rich area for research.

Infrastructure, the Environment, and Disaster

There are very few considerations in the disaster and environmental literature that discuss how minorities and impoverished communities and households suffer disproportionately because lack of infrastructural integrity; usually explained by the inheritance of older and poorer quality housing by low-income and minority folks that can be further explained through the legacy of black urbanization and neighborhood planning forces and inequalities (Van Zandt et al., 2012). Few scholars have discussed infrastructures' relationship to environmental injustices or social vulnerabilities.

Further, none have systematically attempted to measure disparities in infrastructure that would result in inequitable hazard outcomes across social groups. At the time of this review, only three pieces EJ scholarship have explicitly mentioned infrastructure, critical infrastructure, or discussed it in the way its commonly defined, one very recently and only six social vulnerability pieces of scholarship have discussed it. Other mentions of infrastructure in the broader literature either explicitly mention infrastructure, but fail to talk about EJ and SV or discuss EJ and SV, but don't explicitly mention critical infrastructure. Table 2.1 below gives the articles from EJ and SV and their mentions of infrastructure.

The work that does begin to get after this question discusses to some extent how these environmental features can potentially support resistance to environmental threats when well planned, managed, and maintained or in contrast sustain and exacerbate exposure and damage when these same features are ill guided, have poor condition, and outdated capacities (Van Zandt et al., 2012) For example, Bullard (2009) discusses the city of New Orleans' coastal wetlands, which normally serve as a natural buffer against storm surge, and how they have been destroyed by offshore drilling, levees, canals for navigation, pipelines, highway projects, agricultural and urban development. These types of ill-guided gray structural interventions can exacerbate vulnerabilities. Researchers, policy makers, and environmentalists, for decades have called for the restoration of wetlands and barrier islands to help protect New Orleans the next time a hurricane strikes (Bullard. 2009). Hurricane Katrina demonstrated that the negative effects of misguided and poorly maintained storm water management systems fall heaviest on the poor and people of color. Integrity of infrastructure measures the quality of equipment, original construction, and current condition. Integrity produces better reliability, improved service, lower risk, greater safety, improved public health and environmental stewardship, and protection against flood damages (Grigg, 2012). The provision of safe water, adequate sewer, and stormwater services by local municipalities to unserved and underserved residents can help prevent disease (Wilson, Heaney, Cooper, and Wilson 2008).

Lastly, some emerging work also mentions how infrastructure can contribute to risks through direct or residual exposure (Burby, 2001). There are certain elements of each that can contribute to the attenuation or amplification of any given vulnerable area. For instance, Susan Cutter and colleagues (2000) discuss how vulnerable groups that are distant from evacuation routes or downstream from a dam will be at greater risk. The literature goes on to say that critical stormwater infrastructure works when we define ''works'' as protecting a community from routine floods. A flood of record can breach flood control infrastructures, and stormwater structures built to protect one community may result in a greater flood hazard in other communities across the river or downstream from the originally intended protected community (Birkland et al 2003).

A few segregation scholars have alluded to and Robert Bullard specifically has indicated that the infrastructure of urban environments is old, outdated and in disrepair, especially in communities of color (Bullard, 1994). Infrastructure conditions may be associated with segregation related factors, including the distribution of wealth, geographic patterns of racial and economic discrimination (e.g. redlining), housing practices, and a lack of comprehensive planning (Massey & Denton, 1993; Bullard, 1994). Bullard challenges the nation to redefine "environment" to include infrastructure problems that threaten the fabric of our cities and their inhabitants. He discusses how an inadequate sewer treatment plant is an environmental and health threat. The repairing or replacing of decayed sewer lines and upgrading existing and building new sewer plants, as examples of infrastructure, are investments in America (Bullard, 1994). Infrastructures as basic amenities are the building blocks of neighborhoods. In many cases, neighborhoods without basic amenities are less resilient to environmental hazards and weather-related threats, as seen in underserved New Orleans neighborhoods impacted by Hurricane Katrina. (Wilson et al., 2008). Wilson and colleagues (2010) conclude that more work needs to be done in future research to include physical parameters (e.g. infrastructure) in order to improve our understanding of justice and vulnerability so that mitigation, protection and adaptation policies can be better targeted to the most vulnerable, susceptible, and disadvantaged communities and populations (Wilson et al., 2010).

Table 2.1. Selected Mentions of Infrastructure in the Social Vulnerability and Environmental Justice Literatures

Source	***Excerpts***
Social Vulnerability	
Mileti, 1999	Disaster losses result from the Interactions among three major systems: the physical environment, which includes environmental hazards; the social world; and the buildings, roads, bridges, and other components of the constructed environment
Cutter, Mitchell, & Scott, 2000	Public infrastructure—are influential in amplifying or reducing overall vulnerability to hazards
Cutter, Boruff, & Shirley, 2003	The quality of human settlements (housing type and construction, infrastructure, and lifelines) and the built environment are also important in understanding social vulnerability, especially as these characteristics influence potential economic losses, injuries, and fatalities from natural hazards

Table 2.1. Continued

Source	***Excerpts***
Kappes, Papathoma-Köhle, & Keiler, 2012	Infrastructure and agriculture are very important for a community. Disruption of transport routes and lifelines can make the work of rescue teams very difficult. Damages on agriculture will have a significant impact on the economy of the area. For this reason, in a future development of the present methodology, data regarding the physical vulnerability of infrastructure and agriculture should be included
Van Zandt et al., 2012	The foundation of vulnerability analysis, a hazards assessment, generally focuses on a community's exposure to hazard agents such as floods, surge, wave action, or winds (Deyle et al. 1998; NRC 2006, 72–3). Such assessments identify the potential exposure of populations, businesses, and the built environment (housing, infrastructure, critical facilities, and so on). Also important are the physical characteristics of the built environment such as wind design features of buildings, the height of structures relative to potential floods, as well as natural and engineered environmental features such as wetlands, dams, levees or sea walls, because these can modify vulnerabilities and concomitant risk

Table 2.1. Continued

Source	***Excerpts***
Highfield, Peacock, & Van Zandt, 2014	It has long been assumed that racial and ethnic minorities experienced greater damage because they lived in more structurally vulnerable (i.e., poorer quality) homes in more physically vulnerable (e.g., lower-lying) areas. Our findings indicate an independent effect for minority status and lower incomes. While additional research is needed, we suspect that greater damage stems from disinvestment in the community—poorer upkeep, a lack of infrastructure, and regular maintenance, etc.
Cutter et al., 2014	Integrating climate change action in everyday city and infrastructure operations and governance (referred to as “mainstreaming”) is an important planning and implementation tool for advancing adaptation in cities. By integrating climate change considerations into daily operations, these efforts can forestall the need to develop a new and isolated set of climate change-specific policies or procedures. This strategy enables cities and other government agencies to take advantage of existing funding sources and programs, and achieve co-benefits in areas such as sustainability, public health, economic development, disaster preparedness, and environmental justice.

Table 2.1. Continued

Source	***Excerpts***
Environmental Justice	
Bullard, 1994	The physical infrastructure of central cities is old and in need of repair. The physical infrastructure includes roads and bridges, housing stock, schools, job centers, public buildings, parks and recreational facilities, public transit , water supply, wastewater treatment, and waste disposal systems... Institutional barriers and discriminatory public policies con- tribute to urban infrastructure decline, reduce wealth accumulation, and add risks for African Americans.
Bullard, 1994	The nation must redefine "environment" to include infrastructure problems that threaten the fabric of our cities and their inhabitants. An inadequate sewer treatment plant is an environmental and health threat. The repairing or replacing of decayed sewer lines and upgrading existing and building new sewer plants are investments in America.
Wilson et al., 2008	The failure of municipalities to install up-to-code sewer and water infrastructure (i.e., underground sewage and drinking water pipes of the adequate size and material) can lead to vulnerabilities in the sewer and water systems, increased levels of harmful microbes and chemicals in residential drinking and surface water supplies, elevated exposure risks, increased occurrence of gastrointestinal (GI) and other illnesses, reduced neighborhood quality of life, and higher stress levels among poor people of color residents.

Table 2.1. Continued

Source	***Excerpts***
Greenberg, 2016	Urban water systems were designed to deliver safe potable water. How ludicrous and sad it is that we have spent tens of billions of dollars to protect the public against terrorists and remove toxins from raw water before we push it through the system, only to find that the potable water is incompatible with the delivery system and is an equal or even worse threat than deliberate contamination and water pollution. Older cities such as Flint are undermined by badly deteriorated infrastructure.

Hazard Risks and Exposure: Linking Critical Infrastructure

This work argues that the societal distribution of critical infrastructure as a community element can affect daily environmental conditions and vulnerability and thus produce differential impacts from environmental extremes, such as flooding. In the environmental planning literature, the current prominent paradigm is the Environmental Justice approach, which describes how some individuals, groups, and communities receive less protection than others because of their race, ethnicity, national origin, and economic status. Moreover, low-income communities and communities of color bear a disproportionate burden of the nation's environmental problems and occupy spaces where built environments are the opposite of prosperous. In the hazard mitigation and disaster planning literature, the current prominent paradigm is the Social Vulnerability approach, which describes how social stratification based on race, income, disability, gender, age, nationality, among others contributes to differential risks and impacts from disasters.

Environmental justice and social vulnerability are complimentary at the core in terms of community race, ethnicity, and class and that the built environment is exactly the physical manifestation of social circumstances that have been discussed in both the disaster and environmental justice literatures. For example, Shannon Van Zandt and colleagues (2012) discuss how housing, infrastructure, the built environment, and other physical inequalities exist across coastal cities setting the stage for disparities at every stage of the disaster cycle for certain areas; neighborhoods are not made equal, and some are pockets of prosperity and others of disadvantage. The quality of neighborhoods (housing type and construction, infrastructure, and lifelines) and the built environment by way of social circumstances are important in understanding potential economic losses, injuries, and fatalities from natural hazards (Cutter et al., 2003). Social vulnerability is a multifaceted concept that includes dimensions of physical and constructed variables that can help to identify experiences of communities that may or may not support them during environmental hazard exposure. Cutter et al. (2003, p. 258) state that, "the development and integration of social, built environment, and natural hazard indicators will improve our hazard assessments and justify the selective targeting of communities for mitigation based on good social science, not just political whim." The literature has shown significant relationships between damage and hazard exposure, physical characteristics, and social characteristics, which corroborate the need to address hazard exposure and the intersection of environmental injustices and social vulnerabilities as part of fundamental planning efforts (Highfield, Peacock, & Van Zandt, 2014; Kappes, Papathoma-Köhle, & Keiler, 2012). Figure 2.1 provides a theoretical framework to guide planning research and practice for critical infrastructure and hazards risks.

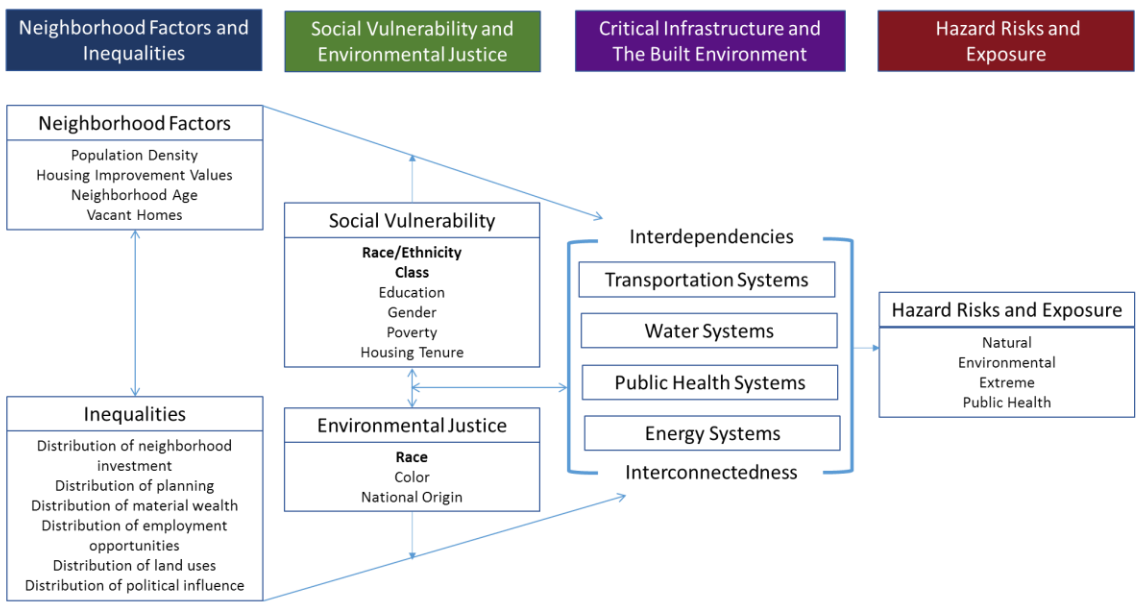

Figure 2.1. Theoretical Framework

The nexus of critical infrastructure, equity and social justice is now being questioned by the rising political and academic interest in these more urban issues such as in how residential segregation can have consequences for communities of color in light of general urban prosperity, climate change and increasing exposures to environmental hazards. However, there has yet to be any published discussion of how the two well-established bodies of literature in Environmental Justice and Social Vulnerability can be merged to expand our understanding of emerging global environmental problems. Likewise, there has been little if any discussion around the provision of infrastructure as well as the designation of maintenance and rehabilitation funding in our capital improvement plans and programming as a mechanism to modify vulnerabilities and environmental outcomes.

CHAPTER III

WATERPROOF: WHERE DO THE BURDENS OF THE STORMWATER “INFRASTRUCTURE CRISIS” FALL HEAVIEST?

Summary

The burden of the nation's infrastructure crisis might fall heaviest on communities of color. Likewise, environmental justice and social vulnerability scholarship indicates that communities of color may be unequally protected from urban flooding and environmental hazards. This may be due to outdated development and insufficient infrastructure systems. Open ditches, located in urbanized areas particularly, may be limited in discharging stormwater to protect people and mitigate the inundation of property. This study investigates the inventory and distribution of roadside open ditches, as an insufficient type of stormwater infrastructure for urbanized areas, related to neighborhood race, ethnicity, and class. Data include an inventory of 2,400 miles of roadside open ditches within Houston, Texas. The analyses use descriptive statistics to describe general patterns of roadside open ditches within Census block groups and multivariate regression models to identify social characteristics associated with the distribution of these stormwater infrastructure systems. Findings show that communities of color are more likely to live in neighborhoods with open ditches and have a greater proportion of their roadsides equipped with open ditch systems; with race being the strongest predictor of the proportion of roadside open ditches. Likewise results suggest

that urban flood exposure might be greater in communities of color due to the greater amount of open ditch systems existing in these neighborhoods. Outdated, insufficient, and declining infrastructure systems might be the reality for minority communities across the U.S. Future research on stormwater and other types of infrastructure systems is needed to determine if this is the case.

These findings reveal opportunities for the replacement of open ditch systems with alternative and current development systems or the retrofitting of these open ditch systems to green infrastructure or low-impact development standards. Addressing these needs could promote for environmental justice and the fair planning and distribution of infrastructure systems and further reduce everyday impacts and hazard exposures in communities of color.

Keywords

Communities of color, stormwater infrastructure, hazard mitigation, flooding, environmental justice, social vulnerability to disaster

Introduction

An infrastructure crisis exists across American cities, which has generated a prevalence of outdated development and insufficient and declining systems (Stein, 1988; Bullard, 1994; Liu, Chen, & Peng, 2014; Cutter, 2014). Infrastructure events, from the collapsing bridges of California to the overflowing storm drains of Houston, are headline grabbing news (Surowiecki, 2016; Olen, 2015; Moss Kanter, 2015; Reid, 2008). Infrastructure systems are past their prime and decaying is omnipresent, but where and on whom do the burdens of decaying infrastructure fall heaviest remains an open question. While several articles have discussed and examined the shortfalls of our nation's infrastructure, little attention has been paid to disparities within this crisis. "Communities of color" – neighborhoods consisting of predominately black, Hispanic, Native American, and/or other ethnic minority residents – are unequally protected from environmental burdens and underserved in the provision of public goods, particularly for infrastructure. Likewise, communities of color are most impacted by disasters and the last to recover from its devastation, which might be the result in some part of outdated infrastructure.

In this study, I use two theories to explain the potential link between insufficient infrastructure in communities of color and resulting disaster impacts. The first theory, Environmental Justice (EJ), focuses on how certain communities are unequally protected from environmental burdens and targeted for the siting of toxic facilities because of their race, ethnicity, national origin, and economic status (Bullard, 2009; Wilson, Heaney, Cooper, & Wilson, 2008; Wolch Byrne & Newell, 2014; Boone et al, 2009; Hernandez, Collins & Grineski, 2015; Landry & Chakraborty, 2009). The second theory, social vulnerability to disaster (SV), focuses on how social stratification based on race, income, disability, gender, age, nationality, among others causes individuals and groups to be differently impacted from disasters (Wisner et al, 2004; Cutter, Boruff, & Shirley, 2003; Morrow, 1999; Phillips et al., 2010; Peacock, Morrow, & Gladwin, 1997; Fothergill & Peek, 2004; Van Zandt et al., 2012). The intersection of these theories allows for the examination of the societal distribution of critical infrastructure that can affect daily environmental conditions and hazard vulnerability and thus produce differential impacts from environmental extremes, such as urban flooding.

In this study, I analyze the inventory and distribution patterns of open ditch systems in Houston, Texas. This study answers two fundamental research questions: (1) what is the general inventory and distribution of open ditch systems and how prevalent are these systems, (2) how do social variables associated with EJ and SV (e.g. race and ethnicity) drive the inventory and distribution of open ditch systems at the neighborhood level?

Results indicate that approximately 45% of all neighborhoods in the City of Houston have some level of roadside open ditch systems for stormwater management. Several neighborhood factors are associated with the prevalence of these open ditch systems. Multivariate modelling shows that when controlling for all other factors that communities of color are more likely to live in neighborhoods with open ditches and have a greater proportion of their roadsides equipped with open ditch systems. Percent black is the strongest predictor of the proportion of open ditches. Neighborhoods with fewer blacks, fewer Hispanics/Latinos, higher population densities, and more expensive homes are less likely to have roadside open ditches, controlling for other neighborhood factors.

I suspect that inequality in infrastructure systems is not unique to the City of Houston, particularly for communities of color. The City of Houston is the fourth largest city in the U.S., with a population numbering over 2 million. Houston is located in southeastern Texas about 45 miles northwest of the Gulf of Mexico coastline.

Furthermore, Houston is considered one of the fastest growing and most diverse cities in the nation. The structure and function of Houston has great implications for other major urban cities around the country. Thus, the inequalities found in this study raise two issues for policymakers and planners. First, these realities could have some notable consequences for communities in light of everyday economic impacts, disaster damage outcomes, and urban sustainability. Second, planners and policy makers must respond to address these environmental injustices for communities of color by either replacing infrastructure systems with the current most fitting development standard or retrofitting communities' systems to low-impact development and green infrastructure standards.

Theoretical Framework

Roadside Open Ditch Systems: A Type of Stormwater Infrastructure

Stormwater infrastructure is meant to address the need to protect the health, safety and welfare of the public, and to protect property from the inundation of water by safely routing and discharging stormwater from developments (CSIR, 2000). Roadside open ditch systems, a type of stormwater infrastructure, consist of small drainage channels expected to help with roadside stormwater runoff. Open ditches have been traditionally installed to protect rural and agricultural type land uses. Open ditches are likely to fall short of these aforementioned expectations, especially in light of climate change and more intense rainfall events, and thus could be considered an outdated, insufficient, and declining system, particularly for urbanized areas.

Specifically, these systems have some notable limitations including insufficiency to contain high water flows, groundwater contamination, and a financial burden to maintain. First, these systems are inappropriate for densely populated areas with extensive pavement and roadway networks resulting in high amounts of impervious surfaces, which increases peak-flows and water runoff. Limited data exists to gauge open ditches effectiveness in routing water in regard to climate change impacts and high peak-flows. Next, roadside open ditches that have not been treated with native vegetation and upgraded to low-impact development standards appear to be ineffective in reducing environmental toxin levels in stormwater runoff (Stagge, Davis, Jamil, & Kim, 2012; Backstrom, Viklander, & Malmqvist, 2006). Finally, roadside open ditch systems require more regular maintenance than other stormwater management options (i.e., storm sewers or curb and gutter) in order to perform at an optimal level (SMRC, 2016). This maintenance involves mowing, dredging, and removing sediment build up and debris. Across cities, the responsibility for routine maintenance of open ditches usually falls on individual households or neighborhoods in order to protect themselves from flooding. Meanwhile, the maintenance of other systems, for example storm sewers, is entirely provisioned by the municipality due to the special and advanced nature of these types of systems. Empirical evidence on whether open ditch stormwater infrastructure systems of this characterization are located more extensively in marginalized communities has not been systematically examined and is the goal of this paper.

Explanations for the Unjust Distribution of Vulnerable Infrastructure Systems

To understand the distribution of stormwater infrastructure across neighborhoods, several bodies of research are reviewed. First, previous research on environmental justice and social vulnerability of disaster provide frameworks to understand how environmental burdens and disaster impacts that vary across communities and population groups may relate to an unequal distribution of open ditch systems. These bodies of literature highlight how race, ethnicity, and class, the key variables of interest in this study, may correlate with better or worse infrastructure systems. Next, neighborhood factors related to larger urban planning issues are described to address other factors beyond population demographics that may affect the financial resources available for infrastructure development and maintenance, and thus quality of neighborhood infrastructures.

Environmental Justice and Social Vulnerability

EJ and SV variables might help explain the distribution of roadside open ditches because race and ethnicity have been consistently shown to be related to the siting of insufficient built features, environmental burdens, and differential disaster impacts. Several case studies in the EJ literature provide examples that minorities resided in communities selected to host hazardous facilities before the facilities were built, and are also underexposed to health-promoting environmental resources (Taylor, 2014). For example, studies have shown that blacks and Hispanics lived in neighborhoods before incinerators were placed in them (Pardo, 1998; Cole & Foster, 2001). An inventory report from 2007 produced by Robert Bullard and his colleagues show that people of color make up the majority of those living in host neighborhoods within 3 kilometers (1.8 miles) of the nation’s hazardous waste facilities. Furthermore, more than 5.1 million people of color, including 2.5 million Hispanics or Latinos, 1.8 million African

Americans, 616,000 Asians/Pacific Islanders and 62,000 Native Americans live in neighborhoods with one or more commercial hazardous waste facilities. Communities of color tend to also lack health-promoting and activity-inviting environmental resources. Ming Wen and colleagues (2013) found that for green accessibility, Census tracts with higher poverty or greater percentages of blacks or Hispanics were underexposed to green spaces. Even in cases where public goods do exists, Taylor and Garrett (1999) found that the quality of management and maintenance of these goods was poor and the level of public resources being spent to attract new users was minimal to none.

The social vulnerability literature offers a way to understand natural hazards and how social stratification and position in society affects disaster impacts for various groups. In New Orleans, during and following Hurricane Katrina, Bullard and Wright (2009) show that neighborhoods that were in the range of 75 to 100 percent Black in 2000 were flooded in 2005. Likewise, they point out that in May of 2008 following Hurricane Katrina, black storm victims were more than twice as likely as white storm victims to still be living in temporary housing. Beverly Wright’s independent work (2011) goes on to show that changes in levee protection, an infrastructure designed to protect property from extreme flooding and storm surge, were closely related to the racial composition of neighborhoods. In fact, in the mostly white and affluent areas, in contrast to the Black and working class areas, there was 5.5 feet of increased levee protection. Furthermore, Highfield, Peacock, and Van Zandt (2014) show that even after controlling for a variety of spatial, structural, and socioeconomic characteristics, homes located in areas with higher proportions of both Hispanic and blacks were found to have experienced more damage following Hurricane Ike. This body of work demonstrates that not only are communities of color plagued with environmental burdens, and these same communities lack opportunities to benefit from public goods that can ultimately minimize risks and vulnerabilities and provide environmental justice.

Race, ethnicity, and economic class are traditional variables used in both EJ and SV theory to account for environmental burden and disparate impact. In a neighborhood planning context, race and ethnicity, correlated with class, are the primary variables in which planning and development have been historically and are currently bestowed upon a neighborhood. Likewise, the inequalities in planning and development are usually driven by these same variables. EJ and SV variables provides evidence that can help explain the distribution of roadside open ditches because race and ethnicity have been consistently shown to be related to the siting of insufficient built features, environmental burdens, and differential disaster impacts.

Neighborhood Factors

There are certain social forces and larger planning and development patterns shaped by power and privilege that can been linked to the prevalence of open ditch systems, as well as demographics and environmental risks. These patterns include urban sprawl, suburbanization, segregation, aging neighborhoods, and urban decay (Hirsch et al, 2016; Delmelle & Thill, 2014; Rohe, 2009; Le Goix, 2005; Frumkin, 2002; Pastor, 2001). These same forces have led to or exacerbated depopulation, the isolation of certain groups, older and abandoned neighborhoods, deflated tax bases, and built environments in disrepair (Marsh, Parnell, & Joyner, 2010; Van Zandt, 2007; Squires &

Kubrin 2005; Seitles, 1998; Silver, 1997; Massey & Kanaiaupuni, 1993). These same forces are coupled with purposeful and systematic discriminatory planning (i.e. racial zoning, private restrictive deeds, and racial steering), neglect, disinvestment, and failure to update and retrofit neighborhood infrastructures (Liu, Chen & Peng, 2014; Isaacson, Gudell, Miller & Wiese, 2014; Badger, 2013; Marsh, Parnell, & Joyner, 2010; Crane & Manville, 2008; Wilson, Hutson, & Mujahid, 2008; Squires & Kubrin 2005).

In this study, population density and vacancy rates are control variables identified neighborhood factors used to account for urban sprawl. Because open ditches have been used more often is less dense areas, location of these infrastructures may relate to areas with smaller densities and also areas identified as declining with high vacancy rates. If race, ethnicity, or class correlate with density or vacancy rates, these neighborhood factors may better explain the provision of open ditches than demographics alone. Housing improvement values are used to account for economic bases available in a neighborhood and potential sources of funding for capital improvement such as storm sewer installation and maintenance. Neighborhood age is accounted for because age may relate to the type of stormwater infrastructure in a neighborhood and also may correlate with race, ethnicity, and class of residents to explain any demographic variation in open ditch systems. Further discussion of how these variables are operationalized is discussed in the methods section. Together, population density, neighborhood age, housing improvement values, and vacancy rates are controlled for to understand the relationship between race, ethnicity, and class and open ditches and any evidence of environmental injustice or social vulnerability identified in this study. Figure 3.1 provides a theoretical framework for how this study was carried out. It includes the stormwater infrastructure, EJ and SV, and neighborhood factors variables of focus and connections that have been discussed thus far. More specifically, it shows from left to right how the identified neighbor factors might be driving the distribution of roadside open ditches with EJ and SV moderating those relationships.

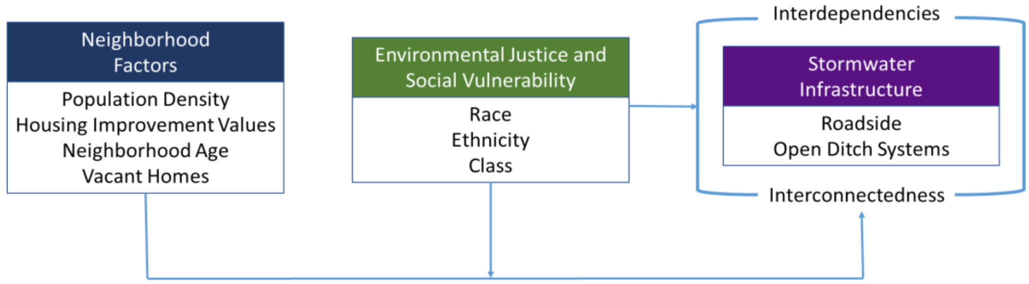

Figure 3.1. Theoretical Framework for the Distribution of Roadside Open Ditch Systems

Methods

This study attempts to measure the distribution of roadside open ditches across an urbanized area, with a particular focus on communities of color. Furthermore, this study assesses which of the narratives or theories described above, using neighborhood level variables, explains the observed distribution patterns. This study evaluates the distribution of roadside open ditches by calculating the proportion of roadside open ditches at an aggregate neighborhood level through the use of geographic information sciences and secondary U.S. Census data. Streets, drainage ditches, and storm sewer infrastructure assets in the City of Houston are managed by the Street and Drainage Division, within the Department of Public Works and Engineering. The Stormwater Maintenance Branch within this Division handles the operation and maintenance of the storm drainage system infrastructure as it is currently configured consisting of 3,800 miles of storm sewer lines and 2,400 miles of roadside ditches (both sides of street) over a 600 square mile region. More specifically, for ditch maintenance, upon request the city will re-grade ditches that become heavily silted; other routine maintenance activities (i.e. mowing, removing weeds, clearing of rubbish, brush, or debris) per city code of ordinance is the abutting property owner's responsibility. These two systems provide stormwater management and flood protection for Houston residents.

Data Sources and Unit of Analysis

The location of open drainage channels and roadside ditches in the form of Geographic Information System (GIS) shapefiles were obtained from the Houston Housing and Community Development Department by the Texas Low Income Housing Service through a Public Information Act request submitted to the City of Houston in November of 2014. The dataset consists of approximately 2,400 miles of open ditch systems across over 1,500 Census block groups in Houston, TX.

The unit of analysis for this study is Census block groups. Block groups are boundary units specially defined by the U.S. Census Bureau to contain between 600 and 3,000 people (U.S. Census Bureau, 2016). The block group boundaries for this study were used based on the 2010 Decennial Census. They were downloaded from the City of Houston GIS Data Portal as the block groups identified as being within city limits. Block groups are used because they are small enough spatial units to provide a proxy for neighborhoods that have relative homogeneity in social makeup (Van Zandt et al., 2012). The roadside open ditch data and all other modeled variables are aggregated to the block group level. Specifically, the roadside open ditch data were overlaid with road data, also available through the Houston GIS Data portal, and the block group layer to create the proportion aggregates at the neighborhood level. Census data from the 2014 American Community Survey 5-year estimates was joined to the dataset using unique identifiers or the block group number.

Measuring Roadside Open Ditches

The roadside open ditches are operationalized as a continuous variable staying true to the nature of the data as offered in distance miles. Because the focus of the study is distribution of roadside ditches at the block group level, the length in miles of roadside open ditches (both sides of street) had to be normalized based on the total length of roads (both sides of street) located within each block group. Therefore, the roadside open ditches were treated as a proportion, bounded between zero and one, by dividing the length in miles of roadside open ditches by the total length of roads multiplied by two (to account for both sides of street). The distribution of critical infrastructure or roadside open ditches, at the time of this study, had not before been operationalized and modeled empirically in this manner. Others have operationalized infrastructure as a binary or dichotomous outcome variable, assuming a Bernouulli distribution, and modeling it through logistic regression (Ariaratnam et al., 2001); statistically modeling infrastructure systems as count data through a Poisson distribution (i.e. Poisson regression, zero-inflated count models, zero-truncated negative binomial, hurdle models, etc.); some mix of generalized additive models (Guikema & Coffelt, 2009); or incorrectly using unfit models in linear or OLS regression.

Measuring Environmental Justice and Social Vulnerability

Environmental justice has been measured either by using spatial proximities, thresholds and indicators, correlations, or descriptive statistics to indicate the association between neighborhood demographics such as race/ethnicity and environmental burdens (Bullard & Lewis, 1996; Hernandez, Collins & Grineski, 2015; Landry & Chakraborty, 2009; Romley et al., 2007; Wolch Byrne & Newell, 2014; Boone et al, 2009). Social vulnerability has been measured either by using index construction (e.g., Cutter, Boruff, & Shirley, 2003); individual level social attributes, such as race/ethnicity, gender, age, socioeconomic status, etc. (Bolin, 1986; Bolin and Bolton, 1986; Peacock and Girard, 1997; Zahran et al., 2008; Zhang and Peacock, 2010); or both approaches (Van Zandt et al., 2012; Peacock et al., 2012).

Because this research represents an initial attempt to assess the merits of environmental justice and social vulnerability relative to infrastructure distribution at an aggregate neighborhood level, three demographic variables known to highly affect environmental and disaster outcomes are employed. The first two are related to race and ethnicity: population counts of non-Hispanic Black and Hispanic/Latino populations were collected from the American Community Survey (ACS) 2014 (5-year estimates) at the block group level and transformed into percentages by dividing these counts by total populations counts and multiplying by 100. Median household income was used as a proxy for socio-economic status also collected from the ACS 2014 (5-year estimates) at the block group level per $1,000.

Measuring Neighborhood Factors

Neighborhood factors that have been linked to larger planning and development patterns and act as proxies at the neighborhood level include population density, housing improvement values, neighborhood age, and vacancy rates. Data on total population were collected from the ACS 2014 (5-year estimates) and population density was calculated by dividing the total population by the block group area in square miles. Mean improvement value for structures within the block group were used as a proxy for local tax bases, which were collected from the Harris County Appraisal District property value roll for 2014 per $10,000. Percent vacant homes was also collected via the ACS 2014 (5-year estimates) and calculated by dividing the total vacant homes by total homes and multiplying by a 100. Lastly, age of the neighborhood and housing stock may reflect the type and quality of infrastructure available at the time of the development. Data on the median age of the structures were collected from the ACS 2014 (5-year estimates) and neighborhood age was calculated by subtracting the median structure built date from 2014.

Descriptive and Multivariate Analyses

Descriptive and summary analyses were conducted to examine the inventory, distributions, and prevalence of roadside open ditches (Research Question 1). A zero-inflated beta (ZIB) regression model was used to confirm the results of the descriptive analyses and assess the relative influence of three factors related to EJ and SV to the distribution of open ditch systems; race, ethnicity, and class (Research Question 2). Data was summarized in contingency tables, histograms, and box plots to assess normality and linearity. As the data was non-normal and inflated at zero, a ZIB regression model was warranted and used (Buis, 2010; Cook et al., 2008; Ferrari & Cribari-Neto, 2004; Papke & Wooldridge, 1993; Paolino, 2001; Swearingen, Castro, & Bursac, 2012).

The ZIB model was estimated using Maarten Buis's ZOIB program, made available through statistical software components (SSC) (Buis, 2010; Cook et al., 2008; Ferrari & Cribari-Neto, 2004). The ZOIB model consists of three parts: a beta model for the proportions between zero and one, a logistic regression model for whether or not the proportion equals zero, and a logistic regression for whether or not the proportion equals one (Buis, 2010; Cook et al., 2008; Ferrari & Cribari-Neto, 2004; Papke & Wooldridge, 1993; Paolino, 2001; Swearingen, Castro, & Bursac, 2012). For this analysis, only the ZIB part of the model was used because the data was inflated at the zero and not the one. The data was zero-inflated because the stormwater infrastructure data for the City of Houston is dichotomous, with either miles of storm sewers or roadside miles of open ditches, and so areas with only storm sewers have a zero value as they have no roadside open ditches. A major assumption of this study is that if block groups do not have any roadside open ditches then they must be equipped with some level of storm sewers. This assumption is discussed in greater detail in the limitations as it pertains to issues with stormwater infrastructure data collection and management.

Beta regression assumes the dependent variable follows a Beta distribution with two parameters μ and $\emptyset$:

$f(open\ ditches; \mu, \emptyset)$

$$= \frac{\Gamma(\emptyset)}{\Gamma(\mu\emptyset)\Gamma\big((1-\mu)\emptyset\big)} open\ ditches^{\mu\emptyset-1}(1 - open\ ditches)^{(1-\mu)\emptyset-1},$$

$$0 < open\ ditches < 1$$

where $0 \leq \mu \leq 1$, $ø > 0$ and Γ is the gamma function. This parameterization dictates that E(y) = μ and Var(y) = μ (1- μ) / (ø+1) , in which the variance of the dependent variable is defined as a function of the distribution mean μ and the precision parameter ø. Extending generalized linear model theory to accommodate this distribution, parameter estimates obtained in beta regression associate changes in the dependent variable's mean and/or precision as a function of explanatory variables.

Inflated beta distributions incorporate degenerate probability statements producing a mixture density. For zero inflation, a new parameter π0 is added to account for the probability of observations at zero. The subsequent mixture density is:

$f(open\ ditches; \pi_0, \mu, \emptyset)$

$$= \begin{Bmatrix} \pi_0, & if\ open\ ditches = 0 \\ (1-\pi_0) f(open\ ditches; \mu, \emptyset), & if\ 0 < open\ ditches\ < 1 \end{Bmatrix}$$

Again, the above models were estimated by the zero-inflated beta (ZIB) method. However, as a check for robustness and because of great familiarity, ordinary least square (OLS) models were also ran on the open ditch measures. This model yielded substantially similar results, but the ZIB results are presented because this model fits the data better and doesn't rely on normality and other assumptions.

Findings

The Prevalence of Open Ditch Systems

Table 3.1 presents basic descriptive statistics for the dependent and independent variables used in the regression analysis. Results for research question one, indicate that approximately 45% of all neighborhoods in the City of Houston have some level of roadside open ditch systems for stormwater management. The distribution of roadside open ditches at the Census block group level ranged from zero to 86%, indicating that no neighborhoods had open ditches on all roadsides. On average, about 11% of all roadsides within Census block groups had open ditches, with a median of 0, due to the zero inflation. The top 25% of all neighborhoods with open ditch systems have roadsides with between 16% and 86% made up of them.

Table 3.1. Descriptive Statistics of Variables Used in Regression Models

Variable(s)	Mean	Standard Deviation	Minimum	Median	Maximum
Stormwater Infrastructure					
Proportion of Roadside Open Ditches	0.11	0.19	0.00	0.00	0.86
EJ and SV					
Percent Non-Hispanic Black	22.67	27.12	0.00	10.82	100.00
Percent Hispanic/Latino	42.35	29.90	0.00	36.06	100.00
Percent Non-Hispanic White	27.57	28.90	0.00	14.17	99.04
Household Income (2014$, 1,000s)	55.18	38.36	7.65	43.40	250.00
Neighborhood Factors					
Population Density	8157.55	9902.83	41.58	5734.46	2.0e+5
Neighborhood Age (Years)	41.60	14.99	9.00	41.00	75.00
Housing Improvement Value (2014$, 10,000s)	39.33	104.23	0.90	11.62	1619.04
Percent Vacant Homes	12.73	9.91	0.00	11.41	62.45

Figure 3.2 shows how open ditches are distributed across Census block groups in Houston, TX. Darker areas indicate greater proportions of total roadside miles that have roadside ditches.

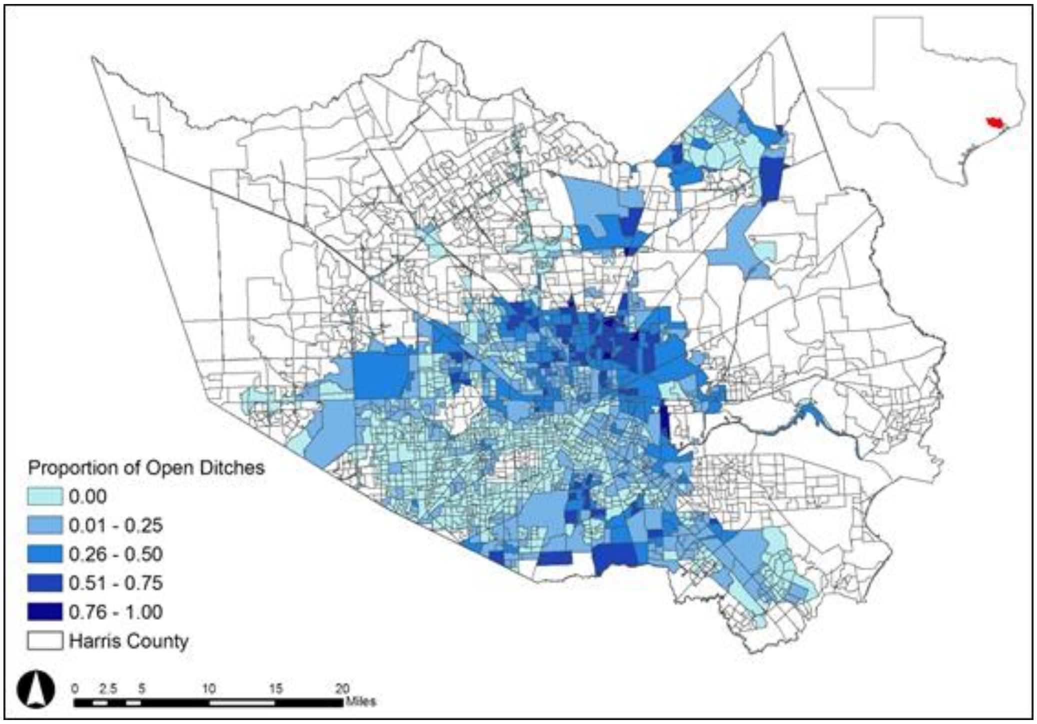

Figure 3.2. The Distribution of Open Ditch Systems

Forty-nine percent of black communities (i.e. neighborhoods with black populations 35% or greater which is the top 25% of black populations in this study), 61% of Hispanic/Latino communities (i.e. neighborhoods with Hispanic populations 68% or greater which is the top 25% of Hispanic populations in this study) and 54% of low-income communities (i.e. neighborhoods with a household income less than $30,000 which is the bottom 25% of household incomes in this study) live in neighborhoods with open ditch systems. 69% of white neighborhoods (i.e. neighborhoods with a white population 50% or greater which is the top 25% of white populations in the study) live in neighborhoods with no open ditch systems. Percent black or Latino population ranges from zero to 100%, with a mean of 23% for black and 42% for Hispanic/Latino. Household income, ranged from $8,000 to $250,000, with a mean of $55,000 and a median of $43,000.

As an example of the distribution of population groups, Figure 3.3 shows where black residents are located in certain Census block groups in Houston, primarily in the south and east of downtown.

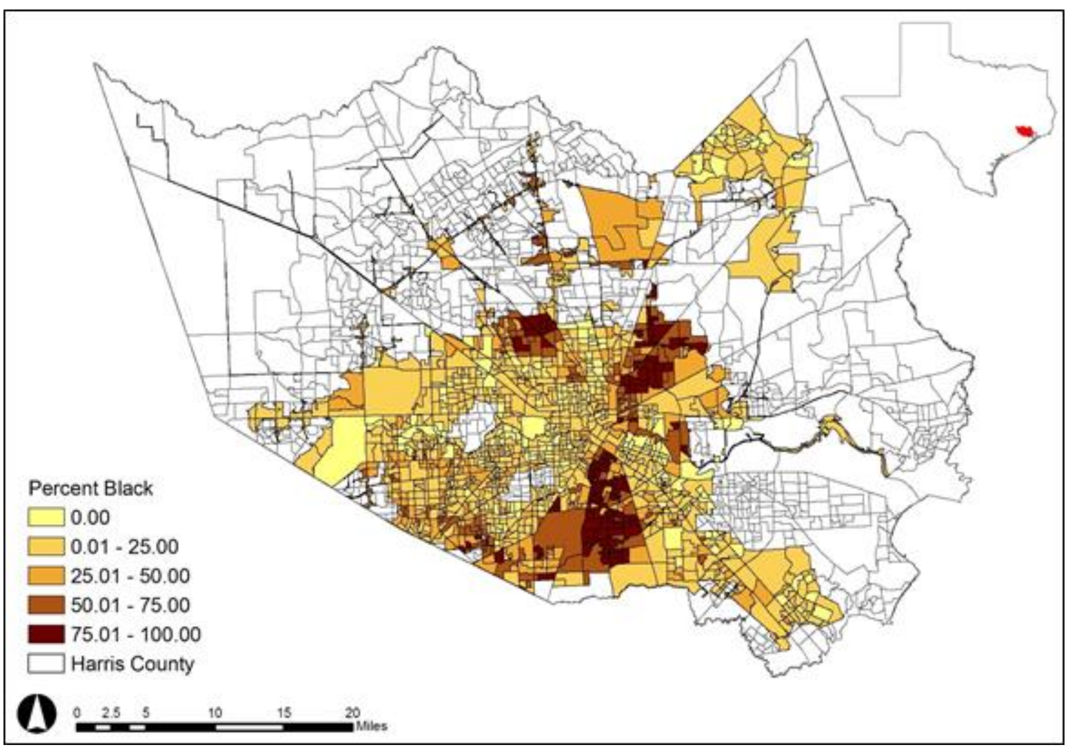

Figure 3.3. The Percentage of Blacks at the Census Block Group Level in Houston

Correlation results are presented in Table 3.2, which display correlations between all the variables included in the regression analyses. Given the EJ and SV research, it is expected that the proportion roadside open ditches, would be positively associated with EJ and SV measures of race and ethnicity, and negatively associated with household income. Meaning that neighborhoods with higher percentages of blacks and Latinos have more of their roadsides equipped with open ditch systems for stormwater management, but as the average income in neighborhoods increases, the amount roadsides equipped with open ditches decreases.

Table 3.2. Correlations of Variables Used in Regression Models with Corresponding P-Values

	Roadside Open Ditches	NH Black	Hispanic/ Latino	NH White	Household Income	Population Density	Neighborhood Age	Housing Imp. Value
NH Black	0.14 <0.00	1.00						
Hispanic/ Latino	0.19 <0.00	-0.36 <0.00	1.00					
NH White	-0.24 <0.00	-0.50 <0.00	-0.58 <0.00	1.00				
Household Income	-0.20 <0.00	-0.39 <0.00	-0.46 <0.00	0.76 <0.00	1.00			
Population Density	-0.19 <0.00	-0.03 0.28	0.14 <0.00	-0.13 <0.00	-0.14 <0.00	1.00		
Neighborhood Age	0.18 <0.00	0.01 0.67	0.25 <0.00	-0.15 <0.00	-0.15 <0.00	-0.09 0.00	1.00	
Housing Imp. Value	-0.15 <0.00	-0.04 0.13	-0.07 0.01	0.07 0.01	0.02 0.40	0.15 <0.00	-0.20 <0.00	1.00
Vacancy	0.05 0.06	0.22 <0.00	0.08 0.00	-0.27 <0.00	-0.28 <0.00	0.04 0.11	0.10 0.00	0.08 0.01

The relationships between roadside open ditches and EJ/SV generally show that neighborhoods more prone to environmental injustices and social vulnerabilities have higher amounts of roadside open ditches. More specifically, the significant positive correlations suggest that neighborhoods with higher percentages of blacks and Hispanics/Latinos have greater amounts of roadside open ditches. Likewise, the significant negative correlation suggests that neighborhoods with more affluent households have fewer amounts of roadside open ditches. On the whole, the significant correlation results for roadside open ditches stay true to their expected relationships and are consistent with the larger planning and development links, as well as EJ and SV theory.

Development Trends: Other Planning and Neighborhood Factors Play a Role, but None Stronger than Race

Bivariate regression results are presented in Table 3.3, which display the individual relationships between the proportion of roadside open ditches and each of the independent variables. These individual relationships are reported to show if and how relationships will change when other variables are controlled for. Based on the individual coefficients for percent non-Hispanic black and percent Hispanic/Latino, 0.008 ($P<0.000$) and 0.002 ($P<0.116$) respectively, as the amount of blacks and Hispanics/Latinos increases, on average the proportion of roadside open ditches systems increases. The individual coefficient for household income, -0.006 ($P<0.000$), shows that as household income increases, on average the proportion of roadside open ditches systems decreases.

The key indicators that are linked to larger neighborhood factors show that the individual relationships for the proportion of roadside open ditches and population density and housing improvement value were negative significant factors for explaining the distribution of roadside open ditches. Meaning that neighborhoods with higher population densities and more expensive homes, on average have fewer amounts of roadside open ditches. The individual relationships for the proportion of roadside open ditches and neighborhood age and vacancy were positive factors for explaining the distribution of roadside open ditches. Meaning that older neighborhoods and neighborhoods with higher vacancy rates, on average have greater amounts roadside open ditches.

Table 3.3. Bivariate Regression Models for Proportion of Roadside Open Ditch Systems

	ZIB (Proportion)				Zero-Inflate (Log Odds)				
	Coeff	***R*(SE)**	***P***	**95% CI**	**Coeff**	***R*(SE)**	***P***	**95% CI**	**Wald chi2**
EJ and SV									
Percent Non-Hispanic Black	0.008	0.001	<0.000	[0.005, 0.011]	-0.002	0.002	0.270	[-0.006, 0.002]	28.44 <0.00
Percent Hispanic/Latino	0.002	0.001	0.116	[-0.0005, 0.005]	-0.017	0.002	<0.000	[-0.021, -0.013]	2.47 0.12
Percent Non-Hispanic White	-0.009	0.002	<0.000	[-0.012, -0.006]	0.014	0.002	<0.000	[0.0097, 0.018]	34.65 <0.00
Household Income (2014$, 1,000s)	-0.006	0.001	<0.000	[-0.009, -0.004]	0.007	0.002	<0.000	[0.004, 0.011]	34.06 <0.00
Neighborhood Factors									
Population Density	-2.76e-5	8.29e-6	0.001	[-4.38e-5, -1.13e-5]	1.40e-4	1.80e-5	<0.000	[1.05e-4, 1.75e-4]	11.07 0.001
Neighborhood Age (Years)	0.009	0.003	0.001	[0.0038, 0.014]	-0.021	0.004	<0.000	[-0.029, -0.013]	11.45 0.001
Housing Improvement Value (2014$, 10,000s)	-0.0036	0.0015	0.020	[-0.007, -0.0006]	0.007	0.002	<0.000	[0.003, 0.011]	5.46 0.02
Percent Vacant Homes	0.007	0.005	0.156	[-0.003, 0.017]	-0.002	0.006	0.748	[-0.013, 0.009]	2.01 0.16

These data confirm previous EJ and SV research on trends in the distribution of environmental burdens and vulnerability outcomes. This analysis shows that race and ethnicity positively influence the amount of roadside open ditches described earlier as a problematic system for stormwater management. Likewise, this data shows that low-income communities on average are less protected by these systems as well.

Multivariate regression models allow assessment of competing explanations for the distribution of roadside open ditches. These models reveal that both neighborhood factors and EJ/SV factors are responsible for the distribution of roadside open ditches. However, as previously stated, variables associated with EJ and SV account for a significant portion of that distribution, however this time, above and beyond general neighborhood factors. Black and Hispanic/Latino neighborhoods on average account for greater proportions of roadside open ditches controlling for household income, population density, neighborhood age, housing improvement values, and vacancy rates. The final zero-inflate model shows that neighborhoods with fewer blacks ($P < 0.001$), fewer Hispanics/Latinos ($P < 0.001$), higher population densities ($P < 0.001$), and more expensive homes ($P < 0.05$) are less likely to have roadside open ditches in their neighborhoods, controlling for other variables in the model.

The results consistently show that, across all independent variables, coefficient signs and effects hold true, with the exception of vacant homes insignificantly changing to a negative effect. Furthermore, the multivariate model shows that above and beyond the neighborhood factors that have been linked to outdated, insufficient, and declining built environments and infrastructure systems, as the percent of black and

Hispanic/Latino increases in a neighborhood, on average roadside open ditches increases by 1 percentage point (P<0.000) and 0.6 percentage point (P<0.008) respectively. For example, a neighborhood that goes from 15% black to 80% black, on average the amount of roadside open ditches is expected to have a 65 percent point increase. Likewise, a neighborhood that goes from 30% Hispanic/Latino to 100% Hispanic/Latino, on average the amount of roadside open ditches is expected to have a 42 percent point increase.

Table 3.4. Multivariate Regression Models for Proportion of Roadside Open Ditch Systems

	ZIB (Proportion)				Zero-Inflate (Log Odds)			
	Coeff	***R*(SE)**	***P***	**95% CI**	**Coeff**	***R*(SE)**	***P***	**95% CI**
EJ and SV								
Percent Non-Hispanic Black	0.010	0.002	<0.000	[0.005, 0.014]	-0.013	0.003	<0.000	[-0.020, -0.007]
Percent Hispanic/Latino	0.006	0.002	0.008	[0.002, 0.011]	-0.031	0.003	<0.000	[-0.038, -0.024]
Percent Non-Hispanic White	[ref]							
Household Income (2014$, 1,000s)	-0.001	0.002	0.436	[-0.005, 0.002]	-0.002	0.003	0.327	[-0.007, 0.002]
Neighborhood Factors								
Population Density	-3.03e-5	9.56e-6	0.002	[-4.90e-5, -1.16e-5]	1.78e-4	2.25e-5	<0.000	[1.34e-4, 2.22e-4]
Neighborhood Age (Years)	0.005	0.003	0.061	[-0.0002, 0.011]	-7.48e-5	0.005	0.987	[-0.009, 0.009]
Housing Improvement Value (2014$, 10,000s)	-0.0004	0.001	0.561	[-0.002, 0.001]	0.004	0.001	0.012	[0.001, 0.006]
Percent Vacant Homes	-0.003	0.005	0.598	[-0.013, 0.008]	0.005	0.007	0.484	[-0.009, 0.018]
Constant	-1.613	0.276	<0.000	[-2.155, -1.071]	0.582	0.410	0.156	[-0.221, 1.386]
N	1,313							
Wald's Chi Square	82.45							

However, the other EJ/SV variable, household income (i.e. class), does lose its significance in the multivariate model. Because Hispanic/Latino goes from insignificant in the bivariate model to significant in the multivariate model and household income goes from significant to insignificant, I suspect that there might be a relationship between class and ethnicity. The reason could be one of two options or both, that are supported by the literature. One, Hispanic/Latino is the largest race/ethnic group in Houston and an established Hispanic population. Some research has shown that with established populations it is harder to marginalize these groups and deny them city services (Lichter et al., 2010) The other possibility is that Hispanics have been shown to be able to assimilate more than blacks and turn economic gains into neighborhood gains (Tran & Valdez, 2015). Yet, history has shown that blacks typically don't have those opportunities.

Discussion

What These Findings Mean for Infrastructure Management, Provision (Levels of Service) and Neighborhood Planning

Infrastructure planning, provision, and potential injustices likely vary from neighborhood to neighborhood and city to city. All systems are not created equal nor do they service communities the same. In Flint, Michigan infrastructural issues may center on corroding pipes, in another city or town it may be an entirely different system leading to other environmental impacts. Open ditches in Houston may be an issue of the future. What binds these types of circumstances is a potential lack of provision and oversight resulting in neglect. Likewise, there is a lack of engagement in understanding how effective these systems are in serving neighborhoods to provide a healthy, safe, and robust level of service. The planning and development of infrastructure systems must be grounded in local conditions and examined separately to determine future needs.

The argument of open ditches as an outdated and insufficient system for neighborhoods in the City of Houston is grounded in the context of high density and urbanization resulting in high amounts of impervious cover and thus creating peak flows that might be beyond the capacity of these systems. Likewise these systems might be outdated simply in terms of development trends for the city and current development codes. Although this study is cross-sectional, newer neighborhoods were less likely to have open ditches. Therefore it seems the development policies might have changed overtime and that these neighborhoods equipped with mostly open ditches were either neglected or targeted for disinvestment. Longitudinal analyses and data on capital improvement projects is needed to determine if this is the case. Open ditches may not ubiquitously be a problematic system. Low-density middle-class neighborhoods with large lots, plenty of green space, and a strong financial capacity might be well-serviced by open ditch systems. However, high density inner city neighborhoods that lack green space, have high amounts of impervious cover, and have an inadequate financial base may have an entirely different experience with these systems. Moreover, communities with poor tax bases might face hardships in terms of their ability to address infrastructure maintenance needs, particularly with open ditch systems. The reality of under-provisioned systems, out-of-date development codes, inadequate levels of service, and financial burdens to maintain make the prevalence of open ditch systems in urban communities of color an environmental justice issue.

Infrastructural disparities are not a result of a single event, act of discrimination, or capital improvement project itself, but rather a series of obstacles structurally built in planning practice, policy and implementation. This urban social structure places certain neighborhoods at substantially higher risk. The provision of safe water, adequate sewer, and stormwater services by local municipalities to marginalized neighborhoods can modify environmental outcomes and experiences related to infrastructure.

Using available data on the type of stormwater infrastructure available in Houston, relationships show that neighborhoods with a higher proportion of black and Hispanic/Latino residents, communities of color, are potentially overburdened and under protected by outdated development such as open ditch systems. This has implications for both individuals and neighborhoods, including the reduction of property values and excess flood exposure and damage. Similar circumstances are likely still in place in other urban areas in the U.S.

The provision or lack thereof of stormwater management has to be strongly considered in communities of color. As discussed above, roadside open ditches are an insufficient form of stormwater management for urbanized areas and inherently have some notable limitations. Some international literature and a growing amount of domestic literature consider open systems to be green, sustainable, and more desirable purely from a natural and unpaved perspective (Sieker et al., 2008; Boller, 2004). However, these systems are only sustainable if these open systems are upgraded to low-impact development and green infrastructure standards, and maintained appropriately. Yet, these green standards still often fail to account for extreme events. This is particularly a concern given growing risks of climate change. Figures 3.4 and 3.5 show photos taken in Manchester, a predominately low-income, Hispanic neighborhood on the east end of Houston. These photos depict how open ditches can easily become unable to provide appropriate levels of service, and thus are not necessarily green, sustainable, or desirable.

Figure 3.4. Site Where Selected Photos Were Taken of Roadside Open Ditches

Figure 3.5. Examples of Open Ditches at Various Condition Levels

What Role Does Race Play in Contemporary Planning and Development in U.S. Cities?

- 50 Years after the Outlawing of Jim Crow

Results from this case study showed that race and ethnicity are consistent predictors of the distribution of roadside open ditches in Houston, above and beyond many neighborhood-level factors that are thought to explain critical infrastructure planning and development. These systems should be retrofitted where possible through the use of green infrastructure and low-impact development standards in order to provide equal protection from flooding for everyone.

More recent development in Houston seem to favor storm sewer systems. Yet some minority neighborhoods have not been able to take advantage of these new developments and that is an environmental justice issue. Overall, in Houston, blacks and blacks of higher income classes are likely still segregated to live in low-income areas characterized by outdated infrastructure systems, older housing stock and other dilapidated structures.

Forecasting Hazard Exposures and Disaster Damage Outcomes

The results also indicate higher risks of urban flood exposure and disaster damage in black and Hispanic/Latino neighborhoods, concerns that will be intensified in light of climate change and sea level rise. According to the American Society of Civil Engineers – Houston Branch (2012), on average, many of the open channels in the Greater Houston area would be inundated by a storm with a 10% Annual Exceedance Probability (AEP). Storms with a 10% AEP, also referred to as 10-year floods have a 10% chance of occurring in any given year. Therefore, with open systems being mostly located in communities of color these communities are at great risk. Immediate next steps of this research is to in fact test the relationship between roadside open ditches and hazard risks and disaster outcomes.

On the contrary, storm sewer systems are usually more efficient in rerouting water away from areas, especially in heavy downpours which are increasing in frequency, and provide immediate protection to neighborhoods with these types of systems. Efficiency is key in situations of intense rainfall or extreme events in order to mitigate exposure and damage outcomes. Likewise, residual flooding can occur when neighborhoods that are equipped with more gray infrastructures, might send even higher peak flows and urban runoff to lower-lying areas. And we know that low-lying areas and flood plains are typically occupied by communities of color (Van Zandt et al., 2012) and we saw in this study that these communities are likely to have open ditch systems resulting in the further overwhelming of these systems. Nevertheless, in Houston communities of color tend to be stuck with older, cheaper, and less efficient open ditches. Infrastructural disparities in other communities of color around the country might help explain findings from the social vulnerability literature in black and Latino communities experiencing greater disaster impacts.

The Limitations: Stormwater Infrastructure Data Collection and Management

This study suffers from a few limitations that have consequences for its generalizability and these limitations in conjunctions with the study findings also suggest opportunities for future research. First, because the City of Houston only offers two types of stormwater management systems, storm sewers and roadside open ditches, it is an assumption that neighborhoods with zero open ditches must be equipped with some level of storm sewer systems. Because stormwater infrastructure data isn't collected, managed, or distributed well, the corresponding datasets are limited. Data for the storm sewers weren't available therefore the distribution of those systems couldn't be modelled for a complete picture of stormwater management. However, the percent white was tested in both a bivariate model and in the multivariate model, excluding black and Hispanic/Latino, and in both models percent white resulted consistently with a negative effect for roadside open ditches. Similarly, percent white was strongly correlated with household income and results showed that as household income increased, the proportion of roadside open ditches decreased. So although future research is warranted in modeling storm sewer systems, I would argue that the assumption of this study is a safe assumption. Also, longitudinal data wasn't available to capture social migration or the turnover of neighborhood infrastructure. Therefore the findings of this study show significant relationships between variables, but can't necessarily be classified as causal. Future research could include longitudinal datasets to understand how changes in neighborhood demographics affect corresponding changes in infrastructures improvements or conversely disinvestment.

Next, Van Zandt et al. (2012) use a suite of other variables (i.e., single and female headed households, housing tenure, poverty, education, public transportation needs, unemployment, etc.) to capture social vulnerability to disaster impacts. However, these variables in a planning context usually manifest out of the isolation and marginalization of neighborhoods through race, ethnicity, and class. Thus, these additional variables aren't used to model the distribution of roadside open ditch systems in this study. Future research could incorporate more indicators of social vulnerability to understand how these other demographics correlate with open ditches.

Lastly, this research was done as a case study for the City of Houston and doesn’t have data for other U.S. cities to compare results. Thus, the findings for this study is that communities of color in Houston have greater amounts of roadside open ditches, more research is needed to confirm and generalize this phenomenon for other areas.

Conclusion

Communities of color are more likely to live in neighborhoods with open ditches and have a greater proportion of their roadsides equipped with open ditch systems.

Results indicate that approximately 45% of all neighborhoods in the City of Houston have some level of roadside open ditch systems for stormwater management. Several neighborhood factors are linked to the prevalence of these open ditch systems. These factors include household income, population density, neighborhood age, housing improvement values, and vacancy, but none stronger than race. Neighborhoods with fewer blacks, fewer Hispanics/Latinos, higher population densities, and more expensive homes are less likely to have roadside open ditches, controlling for all other aforementioned neighborhood factors. Percent black is the strongest predictor of the proportion of open ditches.

I suspect that inequality in infrastructure systems is not unique to the City of Houston, particularly for communities of color. Thus, the planning and development decisions of Houston have great implications for other major urban cities around the country. Furthermore, these inequalities raise two issues for policymakers and planners. First, these realities could have some notable consequences for communities in light of everyday economic impacts, disaster damage outcomes, and urban sustainability. Disproportionate economic and disaster impacts from flooding might be linked to the presence of open ditch systems. Second, planners and policy makers must respond to address these environmental injustices for communities of color by either replacing infrastructure systems with the current most fitting development standard or retrofitting communities' systems to low-impact development and green infrastructure standards. Planning scholars and professionals must begin to effectively use their research, analytical and organizing skills to influence opinion and mobilize underrepresented constituencies to organize around infrastructure issues. Moreover, planners must advance and implement policies and programs (i.e. zoning and land-use controls) that guide development and redistribute public and private resources to help counteract inequalities that plague communities of color.

CHAPTER IV

PAVEMENT AND PROSPERITY: IS THE TRANSPORTATION "INFRASTRUCTURE CRISIS" GREAT ACROSS ALL URBAN NEIGHBORHOODS

Summary

The needs for maintenance and rehabilitation of our nation's transportation infrastructure might be great across all communities. Likewise, due to the interconnected nature of transportation infrastructure, these needs may be spilling over neighborhood boundaries. To better understand roadway infrastructure particularly, at the neighborhood level, transportation equity and environmental justice scholarship warrants us to begin with communities that have been historically disenfranchised. This study investigates the distribution of local roadway condition across urban neighborhoods, related to race, ethnicity, and class. Data include a city-wide pavement condition assessment for Houston, Texas. The analysis uses descriptive statistics to describe general patterns of roadway condition within Census block groups and spatial regression models to identify social characteristics associated with the distribution of these infrastructure conditions, accounting for spatial autocorrelation. Findings show that roadway condition is low for most communities. Contrary to what was hypothesized, communities of color are found to have marginally better condition ratings relative to the rest of the dataset, however of the variables representing communities of color, only

percent Hispanic was found to be significant. Most of these values are still low in terms of pavement and roadway condition. The results warrant more work in this area and longitudinal data to perhaps capture larger phenomena related to social migration and gentrification or transportation-related variables that could explain the findings.

These findings reveal through exploratory analysis that at any one particular point in time it may be difficult to capture disparities in transportation infrastructure condition, however there are methods available that would allow for us to predict these models and control for the presence of spatial autocorrelation. This study suggests that the transportation infrastructure crisis might be great across all communities. Nevertheless, by keeping our fingers on the pulse of infrastructure condition particularly over time can help to inform planning and development for communities of color and surrounding areas.

Keywords

Communities of color, transportation infrastructure, urban development, environmental justice, spatial econometrics

Introduction

Within the U.S. infrastructure crisis, transportation infrastructure has received the most attention for crumbling beneath us (Surowiecki, 2016; Olen, 2015; Moss Kanter, 2015; Reid, 2008). Bridges are collapsing, buses are past their prime, roads badly need repair, airports are dilapidated, trains can’t reach high speeds, and traffic congestion plagues every city (Moss Kanter, 2015). In addressing any type of crisis, history warrants us to pay close attention to the most socially marginalized. While several articles have discussed and examined the shortfalls of our nation's transportation infrastructure, little attention has been paid to disparities within this crisis. Low-income and "Communities of color" – neighborhoods predominately having black, Hispanic, Native American, and/or other racial and ethnic minority residents – are unequally protected from environmental burdens and underserved in the provision of public goods, particularly for infrastructure. Likewise, communities of color are most impacted economically and the last to benefit from revitalization, which might be the result in some part to declining infrastructure (Carlsson, Otto, & Hall, 2013).

Two theories might explain the potential link between unsatisfactory infrastructure in communities of color and resulting economic and community development impacts. The first theory, transportation equity, grew out of the civil rights movement and focuses on how access to affordable and reliable transportation widens opportunity and is essential to addressing poverty, unemployment, and other equal opportunity goals such as access to good schools and health care services. However, current transportation spending programs do not equally benefit all communities and populations. (Karner & Niemeier, 2013; Al Mamun & Lownes, 2011; Iseki & Taylor, 2002; Pendall, Theodos, & Franks, 2012; Aytur et al., 2008). The second theory, Environmental Justice (EJ), focuses on how certain communities are also unequally protected specifically from environmental burdens and targeted for the siting of toxic facilities because of their race, ethnicity, national origin, and economic status (Bullard, 2009; Wilson, Heaney, Cooper, & Wilson, 2008; Wolch Byrne & Newell, 2014; Boone et al, 2009; Hernandez, Collins & Grineski, 2015). The intersection of these two theories allows for the examination of the societal distribution of critical infrastructure that can affect daily socioeconomic conditions and thus produce differential impacts in community development and urban revitalization for communities of color.

In this study, I analyze the distribution of pavement condition ratings (PCR) in Houston, Texas to add to the literature on transportation disparities for communities of color. This study answers three fundamental research questions: (1) what is the general condition of streets in Houston and distribution of PCR across the city?, (2) are there spatial associations in the distribution of PCR at the neighborhood level?, and (3) how do social variables associated with transportation equity and EJ (e.g. race, ethnicity, class) drive the distribution of PCR at the neighborhood level?

Results indicate that 71% of all neighborhoods in the City of Houston have a PCR of less than 70 which is considered unacceptable or failing and in need of immediate rehabilitation. Several neighborhood factors are associated with PCR. Spatial autocorrelation results reveal spatial dependency in PCR across neighborhoods, both between neighbors and in the error term, and require spatial modelling. Contrary to what was hypothesized, spatial modelling shows that when controlling for all other factors that communities of color have marginally better PCR than other communities, however of the variables representing communities of color, only percent Hispanic was found to be statistically significant. Yet, the majority of these neighborhoods still have PCR that are considered failing.

Decaying infrastructure systems are not unique to the City of Houston. The structure and function of Houston has great implications for other major urban cities around the country. The City of Houston is the fourth largest city in the U.S., with a population numbering over 2 million. Houston is located in southeastern Texas about 45 miles northwest of the Gulf of Mexico coastline. Furthermore, Houston is considered one of the fastest growing, most diverse cities, and with one of the largest transportation networks in the country. Thus, the maintenance and rehabilitation needs found in this study raise two issues for policymakers and planners. First, these realities could have some notable consequences for communities in light of everyday economic impacts, productivity outcomes, and urban sustainability. Second, planners and policy makers must respond to address the needs for maintenance and rehabilitation while understanding that transportation infrastructure needs know no boundaries.

Theoretical Framework

Pavement Condition for Transportation Infrastructure Systems

Transportation infrastructure condition can impact the economic climate and social welfare of a neighborhood through its association with new development, economic activity, and opportunities to move people, goods, and services (Litman, 2002; Carlsson, Otto, & Hall, 2013; Haughwout et al., 2001). Paved roads and streets constitute the backbone of transportation infrastructure. Pavement structural thickness and surface smoothness requirements vary according to its intended use; however, there are common performance indicators based on pavement-condition assessments that identify a variety of pavement distresses. Indices that determine pavement condition consider the distress type, severity, and extent (Hudson, Haas, & Uddin, 1997). Such indexes are generally graduated from 0 to 100, where 0 represents the worst of failed condition and 100 represents the best possible condition. A score of 70 and above is usually considered a passing or acceptable score that doesn't warrant immediate attention. There are many types of pavement distresses that determine overall pavement condition. Figure 4.1 provides a few examples of different types of pavement distresses. The American Society for Testing and Materials (ASTM) D6433- 07 Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys Manual provides descriptions of the many types of distresses. The photo farthest to the left represents a combination of depression and block cracking. Depressions are localized pavement surface areas with elevations slightly lower than those of the surrounding pavement. In many instances, light depressions are not noticeable until after a rain, when ponding water creates a "birdbath" area; on dry pavement, depressions can be spotted by looking for stains caused by ponding water. Block cracks are interconnected cracks that divide the pavement into approximately rectangular pieces. Block cracking is caused mainly by shrinkage of the asphalt concrete and daily temperature cycling, which results in daily stress/strain cycling, it is not load-associated. The next photo is an example of lane shoulder drop-off. Lane/shoulder drop-off is a difference in elevation between the pavement edge and the shoulder. This distress is caused by shoulder erosion, shoulder settlement, or by building up the roadway without adjusting the shoulder level. The next photo is an example of corner break. Corner breaks are cracks that intersects the pavement slab joints “near the corner”. A corner break extends through the entire slab and is caused by high corner stresses. The photo furthest to the right is an example of polished aggregate. Polished aggregate is present when close examination of a pavement reveals that the portion of aggregate extending above the asphalt is either very small, or there are no rough or angular aggregate particles to provide good skid resistance. These types of distresses contribute to determining pavement condition rating and are universally recognized by engineers and planners.

Figure 4.1. Types of Pavement Distresses (Left to Right: Depression and Block Cracking, Lane Shoulder Drop-Off, Corner Break, Polished Aggregate)

Explanations for the Unjust Distribution of Decaying Infrastructure Systems

To understand the distribution of transportation infrastructure condition across neighborhoods, several bodies of research are reviewed. First, previous literature on transportation equity and environmental justice provide frameworks to understand how equity issues, environmental burdens, and socioeconomic disparities that vary across communities and population groups may relate to an unequal distribution of roadway pavement condition. These bodies of literature highlight how race, ethnicity, and class, the key variables of interest in this study, may correlate with better or worse infrastructure condition. Next, neighborhood factors related to larger urban planning issues are described to address other factors beyond population demographics that may affect the financial resources available for infrastructure development and maintenance, and thus quality of neighborhood infrastructures.

Transportation Equity and Environmental Justice

Transportation equity and EJ variables might help explain the distribution of roadway pavement condition because race, class and ethnicity have been consistently shown to be related to underserving built features, environmental burdens, and differential socioeconomic impacts. Transportation equity theory grew out of transportation issues that were central to the civil rights movement. During the civil rights movement of the 1960s, much of the discussion about transportation issues for minority and low-income persons revolved around land use patterns and the social and economic conditions of urban areas. In 1968, Dr. Martin Luther King, Jr., described how city planning decisions result in transportation systems that underserve minority communities:

> Urban transit systems in most American cities . . . have become a genuine civil rights issue—and a valid one—because the layout of rapid-transit systems determines the accessibility of jobs to the African-American community. If transportation systems in American cities could be laid out so as to provide an

> opportunity for poor people to get meaningful employment, then they could begin to move into the mainstream of American life. (Sanchez, Stolz, & Ma, 2003; pg. 3)

Transportation equity research specifically, provides examples that low-income and communities of color don't equally benefit from transportation and transportation related plans, policies, investments, and subsidies. For example, studies have shown that while low-income residents generally benefit from some level of public transit subsidy, it's the higher-income and white communities that accrue most of the benefits that they usually don't even need (Iseki & Taylor, 2002). Likewise, Semra Aytur and colleagues (2008) found that land use plans in North Carolina that included transportation improvements and more comprehensive policies to guide development were positively associated with transportation-related activities. However, counties with lower-income levels and higher proportions of non-white residents were less likely to have transportation improvements included in their plans.

The environmental justice literature offers examples of how minorities are unequally served by environmental policies and design. Neckerman and colleagues (2009) discuss how disparities in neighborhood transportation infrastructure conditions may make poor areas less attractive environments both car-dependent forms of mobility as well as alternative modes of transportation including walking, offsetting the possibilities and advantages of modern planning polices and designs (i.e., mixed-use, complete streets). More specifically, through a field observation of a matched-pair sample of 76 block faces on commercial streets, they found that poor Census tracts had significantly fewer trees, landmark buildings, clean streets, and sidewalk cafes, and had higher rates of felony complaints, narcotics arrests, and motor-vehicle accidents than those in nonpoor Census tracts. There is also a growing body of literature that discusses disparities in urban amenities that play a complementary role in transportation infrastructure and can indirectly impact neighborhood desirability. Landry and Chakraborty (2009) show that in Tampa, Florida that there were significantly lower proportion of tree cover on public right-of-way in neighborhoods containing a higher proportion of African-Americans, low-income residents, and renters. This body of work demonstrates that low-income and communities of color have been historically and are contemporarily underserved by built features and lack opportunities to benefit from public goods that can ultimately transform socioeconomic conditions and provide environmental justice.

Race, ethnicity, and class are traditional variables used in both transportation equity and EJ scholarship to account for disparities and environmental burdens. In a neighborhood planning context, race and ethnicity, correlated with class, are the primary variables in which planning and development have been historically and are currently bestowed upon a neighborhood. Likewise, the inequalities in planning and development are usually driven by these same variables. Transportation equity and EJ variables provides evidence that can help explain the distribution of roadway pavement condition because race, ethnicity, and class have been consistently shown to be related to the insufficient maintenance of built features, environmental burdens, and differential development impacts.

Neighborhood Factors

The planning and social forces that have led to unequal maintenance and development even in the absence of formal zoning include, but may not be limited to, private deed restrictions, building ordinances, urban sprawl, Jim Crow laws and laws prohibiting racial intermingling, street and highway planning that have been used as physical mechanisms to separate neighborhoods, the siting of public and affordable housing, and homeownership and home buying discrimination (Rothwell & Massey, 2010; Lipsitz, 2007; Squires & Kubrin, 2005; Seitles, 1998; Silver, 1997). All these social and planning forces impact uneven development and are underlying mechanisms that inform maintenance and provision and most of them predate formal zoning and persisted even after formal zoning in some places to maintain invisible racial zoning and pockets of racial disadvantage. These same forces have led to or exacerbated depopulation, the isolation of certain groups, older and abandoned neighborhoods, deflated tax bases, and built environments in disrepair (Marsh, Parnell, & Joyner, 2010; Van Zandt, 2007; Squires & Kubrin 2005; Seitles, 1998; Silver, 1997; Massey & Kanaiaupuni, 1993).

In this study, population density and vacancy rates are control variables identified as neighborhood factors used to account for urban sprawl. Because roadways are utilized more often in dense areas, location of these various pavement conditions may relate to densities and also areas identified as declining with high vacancy rates. If race, ethnicity, or class correlate with density or vacancy rates, these neighborhood factors may better explain the provision of roadway maintenance than demographics alone. Housing improvement values are used to account for economic bases available in a neighborhood and potential sources of funding for capital improvement such as new road installation and maintenance. Neighborhood age is accounted for because age may relate to the quality of infrastructure in a neighborhood and also may correlate with race, ethnicity, and class of residents to explain any demographic variation in pavement condition. Further discussion of how these variables are operationalized is discussed in the methods section. Together, population density, neighborhood age, housing improvement values, and vacancy rates are controlled for to understand the relationship between race, ethnicity, and class and pavement condition and any evidence of environmental injustice or civil rights issues identified in this study. Figure 4.2 provides a theoretical framework for how this study was carried out. It includes the transportation infrastructure, civil rights and EJ, and neighborhood factors variables of focus and connections that have been discussed thus far. More specifically, it shows from left to right how the identified neighbor factors might be driving the distribution of pavement condition with civil rights and EJ variables moderating those relationships

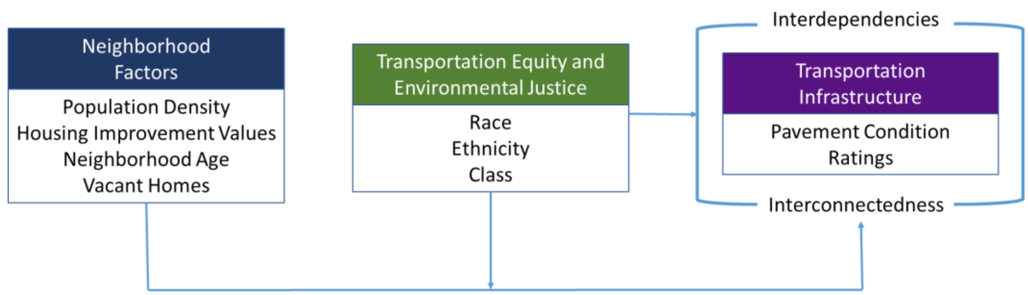

Figure 4.2. Theoretical Framework for the Distribution of Transportation Infrastructure Pavement Condition Ratings

Methods

This study attempts to measure the distribution of pavement condition ratings across an urbanized area, with a particular focus on low-income and communities of color. Furthermore, this study assesses which of the theories described above, using neighborhood level variables, explains the observed distribution patterns. This study evaluates the distribution of pavement condition ratings at an aggregate neighborhood level through the use of geographic information sciences and secondary U.S. Census data. Streets, drainage ditches, and storm sewer infrastructure assets in the City of Houston are managed by the Street and Drainage Division, within the Department of Public Works and Engineering. The Street and Bridge Maintenance Branch within this Division maintains and ensures daily operation of the City of Houston street network which includes 5,700 centerline miles (16,000 lane miles) of paved roadway and 1,382 bridges over a 600 square mile region. This street and bridge network provide travel and mobility opportunities for Houston residents. Houston's streets and roadways are classified into three main categories; major thoroughfares, collector streets, and local streets. Within major thoroughfares there are principal thoroughfares and thoroughfares, and within collector streets there are major collectors and minor collectors. Local streets are standalone roadways and are streets that provide access to individual single-family residential lots, provide entry and exit to the neighborhood, and provide connectivity to collectors and thoroughfares. For this this study, only the local streets were selected for examination because these are the streets that can be identified as a neighborhood level asset. However, there are some potential limitations in dropping all other street types and these limitations are discussed later in this paper.

Data Sources and Unit of Analysis

The location of roadways and pavement condition ratings in the form of Geographic Information System (GIS) shapefiles were obtained from the City of Houston Data Portal interface and titled “Public Works and Engineering (PWE) Street Assessments Layer”. The PCR representing pavement infrastructure condition is a continuous variable and acted as the dependent variable in this study.

The unit of analysis for this study is Census block groups. Block groups are boundary units specially defined by the U.S. Census Bureau to contain between 600 and 3,000 people (U.S. Census Bureau, 2016). The block group boundaries for this study were used based on the 2010 Decennial Census. They were downloaded from the City of Houston GIS Data Portal as the block groups identified as being within city limits. Block groups are used because they are small enough spatial units to provide a proxy for neighborhoods that have relative homogeneity in social makeup (Van Zandt et al., 2012). The PCR data and all other modeled variables are aggregated to the block group level. Specifically, the PCR data were overlaid with the block group layer to create aggregates at the neighborhood level. Census data from the 2012 American Community Survey 5-year estimates was joined to the dataset using unique identifiers or the block group number.

Measuring Pavement Condition Ratings

The City of Houston used a street surface assessment vehicle to conduct pavement assessments for the city between 2010 and 2012. They collaborated with Idea Integration, Inc. to develop the Street Surface Assessment Vehicle (SSAV) with various technologies housed in the mobile unit. The technology systems onboard the vehicle included a road profiler, line scan camera system, accelerometer, 360 degree video, and global positioning system (GPS) and distance measurement instrument (DMI). These technologies collectively allowed for the mobile assessment of pavement distress, capture images, account for vehicle motion, and calculate position of the mobile vehicle. The Pavement Condition Rating (PCR) was calculated according to the following formula:

PCR =100 – (Rutting Deduction + IRI Deduction + Total Cracking Deduction)

The Total Cracking Deduction is a combination of low, medium, and high severity cracking and the final PCR score for a road segment was the average PCR score for the most recent run of each of the lanes driven in the segment. Each category was weighted by a maximum possible PCR point deduction. There was a maximum deduction of 70 points per street segment based on categories including rutting (15 points deducted), roughness (30 points deducted), and cracking (25 points deducted). A PCR score of 30 is the lowest possible score for any segment able to be traveled over by the SSAV.

Measuring Transportation Equity and Environmental Justice

To measure transportation equity and environmental justice at the neighborhood-level, three demographic variables known to highly affect environmental policy and community development are employed. The first two are related to race and ethnicity: population counts of non-Hispanic Black and Hispanic/Latino populations were collected from the American Community Survey (ACS) 2012 (5-year estimates) at the block group level and transformed into percentages by dividing these counts by total populations counts and multiplying by 100. Median household income was used as a proxy for socio-economic status also collected from the ACS 2012 (5-year estimates) at the block group level per $1,000.

Measuring Neighborhood Factors

Neighborhood factors that have been linked to larger planning and development patterns and act as proxies at the neighborhood level include population density, housing improvement values, neighborhood age, and vacancy rates. Data on total population were collected from the ACS 2012 (5-year estimates) and population density was calculated by dividing the total population by the block group area in square miles. Mean improvement value for structures within the block group were used as a proxy for local tax bases, which were collected from the Harris County Appraisal District property value roll for 2011 per $10,000. Percent vacant homes was also collected via the ACS 2012 (5-year estimates) and calculated by dividing the total vacant homes by total homes and multiplying by a 100. Lastly, age of the neighborhood and housing stock may reflect the type and quality of infrastructure available at the time of the development. Data on the median age of the structures were collected from the ACS 2012 (5-year estimates) and neighborhood age was calculated by subtracting the median structure built date from 2012.

Descriptive and Multivariate Analyses

The multivariate approach used in this paper emphasizes the effect of race, ethnicity, and class on transportation infrastructure condition. Specifically, this study employed two models, one being a non-spatial OLS model and the other being a combined spatial autocorrelation model (SAC). In the non-spatial model race/ethnicity, Black and Latino, population groups in Houston, Texas were operationalized as continuous variables and regressed with the PCR Score for transportation infrastructure. The other model this study aimed to take away spatial effects from the non-spatial OLS model by enhancing it through spatial econometric specifications.

Method 1: Regression Model (Non-Spatial OLS Model)

The non-spatial OLS model was empirically specified as:

$$
\begin{aligned}
&Pavement\ Condition\ Rating\ (PCR) \\
&\qquad = f(black + Latino + householdInc + popden + housingage \\
&\qquad + housimpval + vacant)
\end{aligned}
$$

The dependent variable *PCR* is assessed with respect to transportation equity and environmental justice variables (*black, Latino, and household income*) and neighborhood factors (*population density, neighborhood age, housing improvement values, and vacancy rates*).

Method 2: Spatial Models

The Global Moran's Index was used to see if there was spatial autocorrelation in the residuals, this was the first step used in the spatial analysis portion of the paper.

Furthermore, a Lagrange Multiplier test (LM test) was used to find out if significant spatial autocorrelation exists in the OLS residual of the non-spatial model. Given significant autocorrelation, the LM tests were also used to identify the appropriate specification of the spatial model. LM tests have been used widely in the literature of spatial econometrics for this purpose because they have the advantage of not requiring estimation of an alternative hypothesis (the spatial model). LM tests treat the standard model as the restricted model (null hypothesis), and the spatial model as the unrestricted model (alternative hypothesis). Thus, the tests consider the difference between the two models as a situation of omitted variables. LM tests have been commonly used to choose from the most common spatial models: the spatial lag model, or the spatial error model, or a combination of the two. Spatial lag model, or mixed regressive–spatial autoregressive models interpret spatial dependence as a substantial or structural spatial process: a consequence of omitted variables.

Spatial heterogeneity occurs whenever there is clustering in the outcomes across some set of sample units. Spatial autocorrelation can be formally expressed by the moment condition:

$$\mathrm{cov}(y_i, y_j) = E(y_i y_j) - E(y_i) \times E(y_j) \neq 0 \text{ for } i \neq j$$

This covariance becomes meaningful from a spatial perspective when the particular configuration of nonzero i, j pairs has an interpretation in terms of spatial structure, spatial interaction or the spatial arrangement of the observations (Anselin, 2001). In other words, whenever variation in the outcome is not randomly distributed across units (Cook, Hays, & Franzese, 2015). Ignoring spatial heterogeneity can lead to threats to validity of parameter estimates and higher standard errors – which in turn can impact hypothesis testing. In the context of infrastructure, ignoring spatial autocorrelation can lead a researcher to erroneously accept a null hypothesis that the infrastructure elasticity is equal to zero. Further difficulties arise when ignoring a spatially lagged dependent variable, which can lead to biased parameter estimates, implying inaccurate estimates of infrastructure effects (Cohen, 2010). Two mechanisms produce spatial heterogeneity, spatial clustering and/or spatial spillovers. Spatial clustering in the observables or unobservables occurs when the condition, level, or presence of a determinant in one unit is correlated with, but not a function of, the value of that factor in other spatially proximate units (Cook, Hays, & Franzese, 2015). Spatial clustering can also arise due to spatial spillovers, when the outcomes of one unit are a function of the outcomes, conditions, actions, behaviors, and capacities of other units. According to Cook, Hays, & Franzese (2015) this is interdependence and is the spatial effect most commonly assumed by applied researchers. In the context of infrastructure, this idea of spatial interdependencies falls right in line with an interdependency concept in infrastructure research. Infrastructure interdependence means that not only do infrastructural systems sense each other's existence through being interconnected, but are dependent on one another (Zimmerman, 2001). Rinaldi, Peerenboom, & Kelly (2001; pg.14) define infrastructure interdependency as "a bidirectional relationship between two infrastructure networks, through which the state of each infrastructure network influences or is correlated to the state of the other infrastructure." Furthermore, interdependencies are an intrinsic part of infrastructure design and can be a source of a much wider scale vulnerability or disruption than any single system. Making the connection between the idea of spatial interdependence and infrastructural interdependence can be groundbreaking.

Different econometric specifications are needed to determine which combination of the different spatial effects produces spatial clustering in the outcomes and how. Widely discussed models include the spatial autoregressive or spatial lag model (SAR), the spatial error model (SEM), and the combined spatial autocorrelation model (SAC), but only the SAC was employed because the LM tests suggested that dependency existed in both the unobservables and between neighbors. To combat mistakes in hypothesis testing related to spatial spillovers in the observable predictors and unmeasured covariates, spatial econometricians recommend the SAC model as possible two-source model:

$$y = \rho W_y + X\beta + u, u = \lambda W_u + \epsilon$$

The term ρW_y measures the potential spillover effect that occurs in the outcome variable if this outcome is influenced by other unit's outcomes, where the location or distance to other observations is a factor in for this spill-over. In other words, neighbors for each observation have influence to what happens to that observation, independent of the other explanatory variables (X). The W matrix is a matrix of spatial weights, and the ρ parameter measures the degree of spatial correlation. The value of ρ is bounded between -1 and 1. When ρ is zero, the model collapses to the linear regression model. The term u is the residual and measures the error in addition to the potential spillover effect that occurs in the outcome variable if this outcome is influenced by other unit's errors. In addition to study specific theory, empirical indices and tests can be used in determining the types of models one might use in spatial model specification. Of these, the Moran Index and Lagrange multiplier test will be further discussed in the results portion of this paper.

In light of spatial associations and infrastructure, the concentration of decaying infrastructure and its spillover into the condition and capacity of interconnected infrastructures is an additional theme in this paper’s contribution to understanding the endogeneity of transportation infrastructure condition.

Findings

The Prevalence of Decaying Roadway Pavement Systems

Table 4.1 presents basic descriptive statistics for the dependent and independent variables used in the regression analysis. Results for research question one, indicate that approximately 71% of all neighborhoods in the City of Houston have a PCR of less than 70 which is considered unacceptable or failing and in need of immediate rehabilitation. The distribution of PCR at the Census block group level ranged from 55 to 95, indicating that no neighborhoods had a perfect condition rating. On average, Census block groups had a mean and median PCR of 67. The bottom 25% of all neighborhoods have PCRs between 55 and 65. Figure 4.3 shows how PCRs are distributed across Census block groups in Houston, TX. Darker areas indicate worst PCRs.

Table 4.1. Descriptive Statistics of Variables Used in Regression Models

Variable(s)	Mean	Standard Deviation	Minimum	Median	Maximum
Transportation Infrastructure					
Pavement Condition Ratings	67.38	4.22	55.00	67.00	95.00
Transportation Equity and EJ					
Percent Non-Hispanic Black	22.84	27.94	0.00	9.47	100.00
Percent Hispanic/Latino	42.04	29.98	0.00	36.46	100.00
Percent Non-Hispanic White	28.16	28.92	0.00	15.11	100.00
Household Income (2012$, 1,000s)	53.76	37.41	7.00	41.81	250.00
Neighborhood Factors					
Population Density	11475.91	42242.09	20.24	5798.83	1.1e+6
Neighborhood Age (Years)	39.72	14.61	7.00	39.00	73.00
Housing Improvement Value (2011$, 10,000s)	133.86	326.76	0.73	67.07	5814.65
Percent Vacant Homes	13.49	10.92	0.00	11.42	69.76

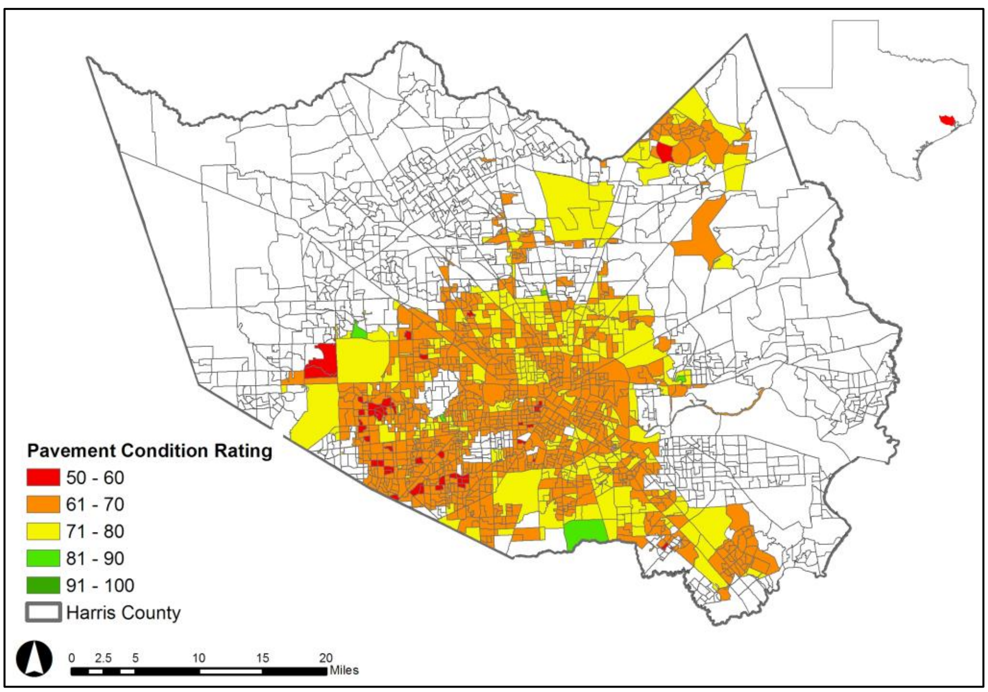

Figure 4.3. The Distribution of Pavement Condition Ratings

Sixty-seven percent of black communities (i.e. neighborhoods with black populations 35% or greater which is the top 25% of black populations in this study), 63% of Hispanic/Latino communities (i.e. neighborhoods with Hispanic populations 69% or greater which is the top 25% of Hispanic populations in this study), 67% of low-income communities (i.e. neighborhoods with a household income less than $30,000 which is the bottom 25% of household incomes in this study), and 77% of white neighborhoods (i.e. neighborhoods with a white population 50% or greater which is the top 25% of white populations in the study) have PCRs less than 70, which are generally considered failing. Percent black or Latino population ranges from zero to 100%, with a mean of 23% for black and 42% for Hispanic/Latino. Household income, ranged from $7,000 to $250,000, with a mean of $54,000 and a median of $42,000.

As an example of the distribution of population groups, Figure 4.4 shows where black residents are located in certain Census block groups in Houston, primarily in the south and east of downtown.

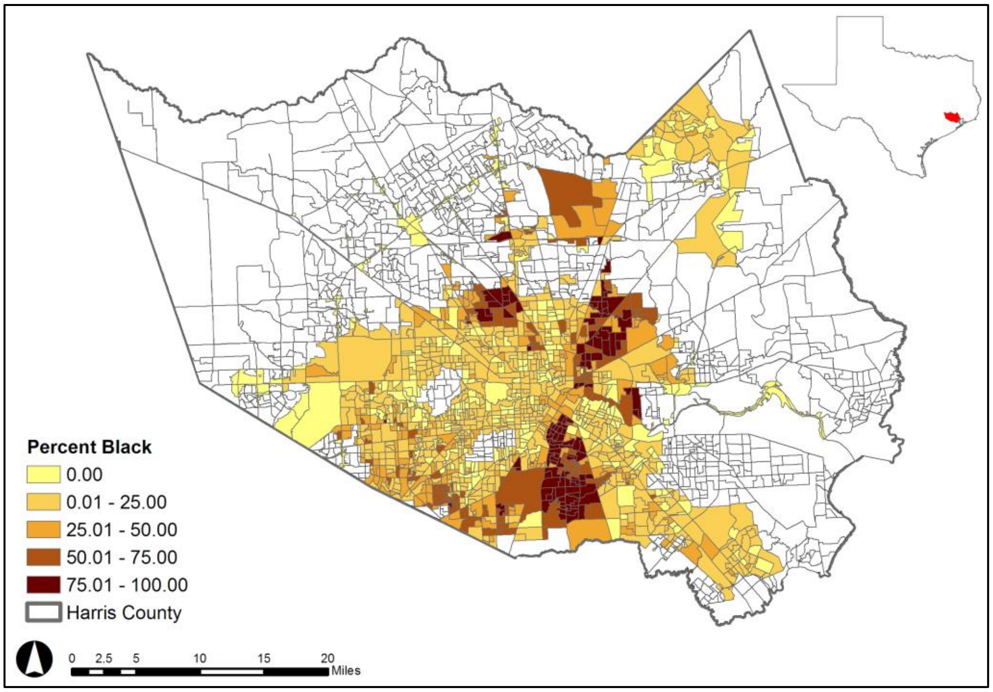

Figure 4.4. The Percentage of Blacks at the Census Block Group Level in Houston

Correlation results are presented in Table 4.2, which display correlations between all the variables included in the regression analyses. Given the Transportation equity and EJ research, it is expected that PCR, would be negatively associated with transportation equity and EJ measures of race and ethnicity, and positively associated with class. Meaning that neighborhoods with higher percentages of blacks and Latinos have worst PCRs and neighborhoods with higher household income would have better PCRs for their local transportation infrastructure.

Table 4.2. Correlations of Variables Used in Regression Models with Corresponding P-Values

	Pavement Condition Ratings	NH Black	Hispanic/ Latino	NH White	Household Income	Population Density	Neighborhood Age	Housing Imp. Value
NH Black	0.04 0.103	1.00						
Hispanic/ Latino	0.18 <0.000	-0.39 <0.000	1.00					
NH White	-0.16 <0.000	-0.50 <0.000	-0.56 <0.000	1.00				
Household Income	-0.12 <0.000	-0.36 <0.000	-0.45 <0.000	0.75 <0.000	1.00			
Population Density	-0.04 0.135	-0.04 0.119	0.07 0.009	-0.04 0.162	-0.01 0.808	1.00		
Neighborhood Age	0.08 0.005	0.03 0.207	0.21 <0.000	-0.14 <0.000	-0.14 <0.000	-0.08 0.005	1.00	
Housing Imp. Value	-0.01 0.841	-0.07 0.014	0.07 0.01	0.05 0.058	0.04 0.156	0.05 0.063	-0.06 0.025	1.00
Vacancy	-0.04 0.118	0.22 <0.000	0.08 0.00	-0.28 <0.000	-0.29 <0.000	-0.01 0.617	0.04 0.146	0.08 0.004

Contrary to hypothesized, relationships between PCRs and transportation equity and EJ variables generally show that neighborhoods more prone to transportation inequalities and environmental injustices have better condition ratings. However, the specific results for each variable representing transportation equity and EJ are very different. Latino has a significant weak positive relationship, household income has a significant weak negative relationship, and black has a non-significant weak/none positive relationship. White has a significant weak negative relationship. On the whole, the correlation results for PCRs are inconsistent and weak or have no relationship with transportation equity and EJ variables.

Spatial Associations in the Distribution of PCR at the Neighborhood-Level

First, the PCR variable was tested for global spatial autocorrelation. Moran's I statistic (Table 4.3) for testing global spatial autocorrelation provides a global statistic. More specifically, it reveals spatial dependency or clustering in PCR across block groups, but it doesn't tell us exactly where or how that spatial dependency is manifested. In order to determine the specific cause of spatial dependency, diagnostics tests for spatial dependence were ran.

Table 4.4 presents LM tests for both error (1614.732; $p< 0.00$) and lag (1587.709; $p< 0.00$) were highly statistically significant. The Robust LM are also statistically significant. Test statistics for spatial autocorrelation reveal that spatial dependency exists both between neighbors and in the error term. Usually, the Spatial Error Model (SEM) accounts for dependency in the error term and the Spatial Lag Model (SAR) accounts for dependency between neighbors. But because both LM tests came back statistically significant, Cook, Hays, and Franzese (2015) advocate that we should practice caution when estimating these models, especially when we attempting to articulate and test specific theories of spatial interdependence, as in the case of this study. Consequently, only the Combined Spatial Autocorrelation Model (SAC) was reported for analysis. This decision was made because the SAC model allows us to discriminate between neighboring spillover and spatial clustering in the error term. This model is used to account for both types of spatial interdependence.

Table 4.3. Measures of PCR Global Spatial Autocorrelation

Weights Matrix		
Moran's I	Statistic	*P* Value
PCR	65.098	0.000

Table 4.4. OLS Test Statistics for Spatial Autocorrelation

Distance Based W		
Spatial Error:	**Statistic**	***P* Value**
Moran's I	54.261	0.000
Lagrange Multiplier	1614.732	0.000
Robust Lagrange Multiplier	106.748	0.000
Spatial Lag:		
Lagrange Multiplier	1587.709	0.000
Robust Lagrange Multiplier	79.725	0.000

Condition Trends: Transportation Infrastructure Condition Is Poor Across All Communities

The spatial regression model (SAC) shows a positive relationship between black (0.012; P<0.068) and Latino neighborhoods (0.014; P<0.020), negative relationship with household income (-0.0006; P<0.873) and PCR (Table 4.5). Controlling for other variables in the model, for every one percent increase in the black population in a Census block group, on average the PCR increases by 0.012. The result for Latino indicates that for every one percent increase in the Latino population in a Census block group, on average the PCR increases by 0.014. For example, if a Census block group increased from 1 percent black or Latino to 100 percent black or Latino, the PCR would be expected to increase on average by only one point. The coefficient for household income is -0.0006, when controlling for other variables in the model. This result indicates that for every one-thousand dollar increase in household income in a Census block group, on average the PCR decreases by 0.0006. This particular variable is not significant in either model. In the SAC model, only Latino (majority ethnic group in Houston), population density and neighborhood age have significant effects on PCR. The two models (OLS and SAC) provide different results and conclusions, showing the importance of spatial regression techniques in these analyses. More specifically, as you move from the OLS model to the SAC model the effect size and the level of significance is reduced. This means that the SAC model provides a more robust estimation of the effects of the variables in the model because it accounts for spatial autocorrelation. These results are also more closely reflective of the correlation relationship results discussed previously.

Table 4.5. Multivariate and Spatial Regression Models for PCR

	OLS				SAC			
	Coeff	**SE**	***P***	**95% CI**	**Coeff**	**SE**	***P***	**95% CI**
Transportation Equity and EJ								
Percent Non-Hispanic Black	0.028	0.006	<0.000	[0.017, 0.039]	0.012	0.006	0.068	[-0.0008, 0.024]
Percent Hispanic/Latino	0.039	0.006	<0.000	[0.028, 0.051]	0.014	0.006	0.020	[0.002, 0.026]
Household Income (2014$, 1,000s)	0.005	0.004	0.298	[-0.004, 0.013]	-0.0006	0.004	0.873	[-0.008, 0.007]
Neighborhood Factors								
Population Density	-5.57e-6	2.66e-6	0.036	[-1.08e-5, -3.59e-7]	-6.04e-6	2.21e-6	0.006	[1.04e-5, -1.71e-6]
Neighborhood Age (Years)	0.004	0.008	0.641	[-0.012, 0.019]	-0.020	0.008	0.015	[-0.035, -0.004]
Housing Improvement Value (2014$, 10,000s)	0.0002	0.0003	0.631	[-0.0005, 0.0008]	0.0004	0.0003	0.165	[-0.0002, 0.001]
Percent Vacant Homes	-0.037	0.011	0.001	[-0.058, -0.016]	-0.004	0.009	0.671	[-0.023, 0.015]
Constant	-1.613	0.276	<0.000	[-2.155, -1.071]	-141.124	8.733	<0.000	[-158.24, -124.01]
N	1,357							
Adjusted R^2	0.06							
Wald Chi Square					23.1263			

Discussion

What These Findings Mean for Transportation Infrastructure Management, Provision, and Neighborhood Planning

The original research question was tri-fold: (1) what is the general condition of local streets in Houston and distribution of PCR across the city?, (2) are there spatial associations in the distribution of PCR at the neighborhood level?, and (3) how do social variables associated with transportation equity and EJ (e.g. race, ethnicity, class) drive the distribution of PCR at the neighborhood level? Likewise, the hypothesis was tri-fold. First, that there is an infrastructure crisis and that transportation infrastructure is decaying and that need for rehabilitation might be great across all communities. Next, that race, ethnicity, and class would further affect transportation infrastructure condition, and last, that spatial models were necessary for correctly specifying these models. The preliminary results did not support the hypothesis in a transportation equity and environmental justice context, but the modeling completed did show the importance of using methods that account for spatial autocorrelation in transportation infrastructure condition. While the result is in contrast to the hypothesis, the size of these coefficients and the lack of statistical significance, particularly for black, indicates that there is little evidence of variation in PCR score based on percent black. Recognizing the lack of significance here is especially important with this variable moving from the non-spatial OLS model to the SAC model because between these two models this variable goes from being highly significant ($P<0.000$) to not significant. Overall, transportation infrastructure conditions appear to be poor, thus resulting in marginal variations across neighborhood boundaries.

When it comes to transportation infrastructure management, provision, and neighborhood planning, this type of infrastructure consisting of primarily streets and roads are relatively much cheaper to repair in comparison to other types of infrastructure. Therefore, smaller level investments can be made in the form of "patch work" that can ultimately impact the scores that come back for pavement condition. Patching is still considered by most assessment methodologies as a type of distress, but could still be counted as less distress than the type the patch was repairing. Transportation infrastructure condition can be volatile again limiting cross-sectional analysis. Also, disaster funding in the form of FEMA, HUD, and CDBG grants can create opportunities for rehabilitation and development, especially for communities that were impacted by the event the most. In recent years, the city of Houston has been hit by Tropical Storm Allison, Hurricane Ike, and multiple historic flooding events. Lastly, larger social events that take place in the city can motivate investment and development especially for neighborhood infrastructure near special districts (central business and historic) and downtown. For the city of Houston specifically these motivations could have come in the form of the recent NBA All-Star game, NFL Superbowls, and several major concerts and festivals.

What Role Does Spatial Autocorrelation and the Interconnectedness of Roadway Infrastructure Play?

The findings from this research show the necessity of spatial models to avoid biased estimations and errors in hypothesis testing due to the interconnected nature of infrastructure systems. Spatial Autocorrelation is a measure of the degree to which a set of spatial features and their associated data values tend to be more similar when close to each other and features that are more distant have values that are less similar. More specifically, according to Cohen (2010), spatial autocorrelation occurs when one locality's error term in a regression depends on "neighboring" localities' shocks or innovations, instead of merely being normally distributed with zero mean, constant variance, and zero variance between observations over time and space. Causes of spatial autocorrelation can include omitted variables that vary spatially, decisions in one location that are made for entities in other locations, using data that are averaged over different sized areas for different geographic units, shocks that spillover across geographic boundaries, measurement error, and simultaneity. One example of how spatial autocorrelation might occur out of shocks that spillover can be referenced in the infrastructure literature that discusses the impacts of public infrastructure capital spillover and the benefits and costs across geographic boundaries (Cohen, 2010). Another example can be found in the environmental justice literature in considering spatial autocorrelation when investigating socioeconomic status and air pollution exposure and using models that account for omitted variables (Havard et al., 2009). Cohen (2010) discusses using the generalized moments procedure (GMM) to accommodate for spatial autocorrelation, while Harvard et al. (2009) uses spatial models such as simultaneous autoregressive models (SAR).

The Limitations: Transportation Infrastructure Issues at the Neighborhood Level

The results warrant more work in this area and longitudinal data to perhaps capture larger phenomena related to social migration and gentrification or transportation related variables that could explain the findings. Social migration and gentrification are important to consider because in urban planning we are on the verge of seeing the slowing of suburbanization and the start of the second wave of urbanization. Millennials, retired baby boomers, and populations in general are starting to find value in city living again. Inherent in these decisions is the movement of people per social forces including gentrification. Gentrification leads to redevelopment and rehabilitation of streets in inner city neighborhoods that have historically been minority. Thus timing of the data collection is important. Transportation related factors include the fact that more affluent and White neighborhoods might own more cars thereby having more traffic and causing the condition of their roads to decline more often. The flip side of that regarding black neighborhoods is that fewer cars and less traffic allows for these neighborhoods to preserve their infrastructure.

Further, removal of the highways and thoroughfares from the dataset, truncated the variation in the dependent variable, therefore this data might not be the best to use to get after the question at hand. This could affect the estimation of effects. This could be an important consideration. In many inner cities compared to suburbs, people live along major throughfares. Thus the distinction as outlined in the secondary data may not accurately represent where people live. Likewise, the assessment technology and methodology can have some inconsistencies as well in data collection. Planners and infrastructure managers only have so many dollars to spend on management and maintenance each year. Currently, data used in the decision making process of where to make capital improvements is limited, anecdotal, and outdated. Even in the use of more advanced technologies such as laser scanning can have limitations in the form of surface scanning restrictions, obstruction of laser beams, distortion of signals, and data processing is required which could have human and statistical error.

Next steps include identifying other infrastructure datasets that are available to continue to further examine these questions of fairness in infrastructure planning and modeling. Furthermore, infrastructure data globally are not collected or maintained well, and future research also includes working with planning officials and communities to help address issues in infrastructure provision and management. An environmental justice research agenda examining the planning, management, and distribution of urban critical infrastructure can enhance everyday services as well as mitigate the negative outcomes of environmental threats (i.e. natural hazards, public health illnesses), especially for marginalized communities by researchers being consistent in making sure potential injustices are not ignored.

Conclusion

Spatial econometrics can be used to explore the interdependencies and broader nature of public infrastructure. Scholars over the past several years have assessed both the impacts of spatial autocorrelation and spatial lags on estimates related to public infrastructure. Various types of transportation infrastructure have been studied, including highway and air assets, however, no work to my knowledge has modeled the condition of transportation infrastructure, especially in a transportation equity and environmental justice context at the neighborhood level and that is an additional contribution of this paper.

Results indicate that 71% of all neighborhoods in the City of Houston have a PCR of less than 70 which is considered unacceptable or failing and in need of immediate rehabilitation. Several neighborhood factors are associated with PCR. Spatial autocorrelation results reveal spatial dependency in PCR across neighborhoods, both between neighbors and in the error term, and require spatial modelling. Contrary to what was hypothesized, spatial modelling shows that when controlling for all other factors that communities of color have marginally better PCR than other communities, however of the variables representing communities of color, only percent Hispanic was found to be statistically significant. Yet, the majority of these neighborhoods still have PCR that are considered failing.

Decaying infrastructure systems are not unique to the City of Houston. Thus, the maintenance and rehabilitation needs found in this study raise two issues for policymakers and planners. First, these realities could have some notable consequences for communities in light of everyday economic impacts, productivity outcomes, and urban sustainability. Second, planners and policy makers must respond to address the needs for maintenance and rehabilitation while understanding that transportation infrastructure needs know no boundaries.

CHAPTER V

CONCLUSION INFRASTRUCTURAL JUSTICE AND FAIRNESS IN SUSTAINABLE DEVELOPMENT

Critical infrastructures play important roles in managing daily environmental conditions and environmental extremes, such as flooding. Increasing exposures to environmental hazards for communities around the country raise questions about the nature and condition of these infrastructures. Further, variations in planning and management of critical infrastructure at the neighborhood level presents concerns for equity, social vulnerability, and environmental justice, since public decisions regarding the distribution of infrastructure affect people's exposure to risk. Therefore, planning research, policies, and programs that address infrastructural justice and fairness in sustainable development are needed.

Through a series of three conceptually linked papers - a literature review and two empirical papers - this research examines the distribution of infrastructure in the context of equity, environmental justice, and social vulnerability to disasters at the neighborhood level. This study examines infrastructure across Census block groups in Houston, Texas to address three questions:

1) What is the general inventory, condition, and distribution of infrastructure systems?

2) How do social variables associated with equity, environmental justice, and social vulnerability (e.g. race, ethnicity and class) drive the inventory, condition, and distribution of critical infrastructure at the neighborhood level?
3) Are there spatial associations in infrastructure condition and distribution at the neighborhood level? And if so, what spatial regression models best account for these associations?

In the two empirical papers, “Waterproof” and “Pavement and Prosperity”, multivariate and spatial regression are used to model two infrastructure datasets across over 1,300 Census block groups in the City of Houston, Texas. The dataset in the first empirical paper, Waterproof, is an inventory dataset for roadside open ditches and the dataset in the second empirical paper, Pavement and Prosperity, is from a city-wide pavement condition assessment.

Regression results from “Waterproof” indicate a positive relationship between black and Latino neighborhoods and the proportion of roadsides that consist of open ditches for storm-water management. Open ditches particularly, are limited in discharging stormwater to protect people and mitigate the inundation of property. Thus, these results support hypotheses related to environmental injustice and social vulnerability. “Pavement and Prosperity” shows that there is spatial dependency across neighborhoods, both between neighbors and in the error term. The appropriate spatial regression model that accounts for these two dependencies show a positive relationship between black and Latino neighborhoods and the better pavement condition ratings. These particular results are contrary to what was hypothesized.

The findings from “Waterproof” inform the need to invest in storm-water infrastructure in communities of color. Roadside open ditches are not the current development standard of the city. Likewise, these systems can be insufficient in light of more frequent flooding due to rapid urbanization and climate change. To function adequately, these systems could be retrofitted to green infrastructure and low-impact development standards. The findings from “Pavement and Prosperity” suggests the necessity of spatial models to avoid biased estimations and errors in hypothesis testing due to the interconnected nature of infrastructure systems. More importantly, the findings show that roadway condition is low for most communities. Contrary to what was hypothesized, communities of color are found to have marginally better condition ratings relative to the rest of the dataset, nevertheless these values are still low in terms of acceptable pavement and roadway condition. This study suggests that transportation infrastructure maintenance and rehabilitation needs are great across all communities.

More specifically, this work offers a number of broader impacts and recommendations for research and practice:

- This study cohesively addresses questions of distribution and equitable treatment of disadvantaged populations and incorporates environmental justice issues into not only public health, but natural hazards. These findings have developed explicit policy and practical implications to improve community sustainability.

- The process of the research itself has motivated the development of methods and tools, which show promise at improving the capacity of marginalized populations to advocate for improved infrastructure on their own behalf. The future development of an infrastructure assessment tool may also broaden public awareness and understanding of existing infrastructure condition and assessment processes.
- This research will be handed off to current community partners and advocates working with residents in highly vulnerable urban areas of Houston, Texas to meaningfully incorporate these empirical results into environmental inquiry, planning, and decision-making. Creating opportunities for neighborhood knowledge feedback loops as a part of a check and balance system provides opportunity for capacity-building and optimal analyses of environmental impact resistance and sustainability.
- The research provides opportunity to breakdown perceived disciplinary barriers in doing environmental research. By incorporating in methods and theory from multiple disciplines it shows the innate origin and interconnectedness of various disciplines in addressing the dynamic nature of environmental research.
- This research informs capital investment and spending for infrastructure management and address issues of neglect and minimize wasteful and concentrated expenditures. Understanding where, when, and how capital investment for infrastructure should be made provides more accountable spending for municipalities.

- This research creates the opportunity for flood and inundation risk and damage estimations and outcomes based on infrastructure condition and distribution.
- Improvements in critical infrastructure driving gentrification and dislocation is alluded to in this work as well (just good and green enough).
- This research illuminates an explicit need for establishing retrofitting policies for open ditch systems in Houston, Texas.
- The collection, management, and translation of infrastructure data at the municipal and community level. (data currently not collected systematically or well maintained)
- Informs methods on modeling infrastructure in a social context.
- Although this research focuses on equity and justice of marginalized groups it as a parallel or spillover impact enhances environmental equity and justice for all.

Summary

"Unequal protection revisited" demonstrates how through EJ and SV variables we can explore infrastructure issues while also understanding how the history of planning or lack thereof for these constructs contribute to disparate impact. It also provides from a community planning perspective how yet again race and ethnicity particularly have to be considered in the distribution of public goods and environmental hazards, especially at the neighborhood level. Race independently and race alone is above and beyond a significant factor by which planning and development decisions are made for American communities.

“Waterproof” shows that minority communities particularly black neighborhoods are overburdened and under protected by outdated development, this is particularly the case with open ditch systems in Houston, Texas. This finding can have meaningful implications for neighborhood level outcomes including property values and flood exposure and damage. Similar circumstances (e.g. outdated development and unmaintained systems) might be the reality for other minority communities in urban areas and major cities around the country.

“Pavement and Prosperity” shows through exploratory analysis that at any one particular point in time it may be difficult to capture disparities in transportation infrastructure condition, however there are methods available that would allow for us to predict these models and control for the presence of spatial autocorrelation. This study suggests that transportation infrastructure maintenance and rehabilitation needs are great across all communities. But by keeping our fingers on the pulse of infrastructure condition particularly over time can help to inform planning and development for communities of color and surrounding areas.

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APPENDIX

Study Area

The City of Houston is home to over 2 million people. Of that population, approximately 50 percent are White, 23 percent are Black, and 43 percent are Hispanic or Latino. The median household income is approximately $45, 728 and almost 23 percent of all persons live in poverty. Houston is located in southeastern Texas about 45 miles northwest of the Gulf of Mexico coastline. Houston is mostly within Harris County, and it and surrounding areas, including Montgomery, Fort Bend, Brazoria, Liberty, Chambers, and Galveston Counties, reside in the coastal plain, which is identified by very flat topography and numerous bayous, creeks, and river systems each with different local issues. The region receives approximately 48 inches of precipitation annually. Moreover, this rainfall is subject to the subtropical climate which produces high intensity rainfall patterns. Since much of the soil in the region includes a high clay content, so that the combination of soils with intense rainfall events tends to produce high water runoff rates (ASCE 2012 Report Card for Houston Area Infrastructure).

The major river system draining the study area is Buffalo Bayou, a tributary of the San Jacinto River. Buffalo Bayou has been regulated by Barker and Addicks flood-detention reservoirs in the western part of the area since the late 1940s. From these reservoirs, Buffalo Bayou flows eastward, is fed by four major tributaries (Whiteoak, Brays, Sims, and Greens Bayous), and enters the Houston Ship Channel and then Galveston Bay on the Gulf of Mexico. The drainage area of Buffalo Bayou, excluding the area upstream of the reservoirs, is about 810 square miles (Liscum, 2001).

Stormwater Management in Houston

Streets, drainage ditches, and storm sewer infrastructure assets are managed by the City of Houston Street and Drainage Division, within the Department of Public Works and Engineering. The Stormwater Maintenance Branch within in this Division maintains the storm drainage system infrastructure as it is currently configured. Storm drainage services are divided into two major systems, the storm sewer system and the open ditch system. The storm sewer system operates and maintains the following assets over a 650 square mile region: approximately 3,800 miles of storm sewer lines and related infrastructure (e.g, manholes, inlets), 6,305 outfalls, and 28 roadway underpasses with storm ponding level warning devices (some with pump stations). The open ditch system is the alternative stormwater management system and is the focus of this study. It contains approximately 2,400 miles of roadside ditches (both sides of street) over a 650 square mile area, 74 miles of off-road/major drainage ditches, and 10 storm water detention basins. These two systems provide flood protection for Houston residents.

Reliability and Validity of Data

The data was determined to be valid and reliable through a triangular method of ground-truthing by way of community engagement, use of satellite technology and imagery, and city website face validation. As an extension of the secondary and empirical research, further research is underway in engaging communities from the area being explored to utilize a participatory infrastructure assessment tool. This process was used as a way to validate on the ground the data being used in the secondary analysis. In addition, other research has been done using Google Street view as a way to do housing damage and recovery assessment following technological hazards. Therefore, this same method was adopted for this research as a way to validate the location and to some degree the condition of infrastructure data. Lastly, the city's website has a thorough description of the type and quantity of the infrastructure that it oversees and these descriptions were used to confirm the validity and reliability of the data.

Waterproof Methods Continued

Building a Zero-Inflated Beta Regression Model

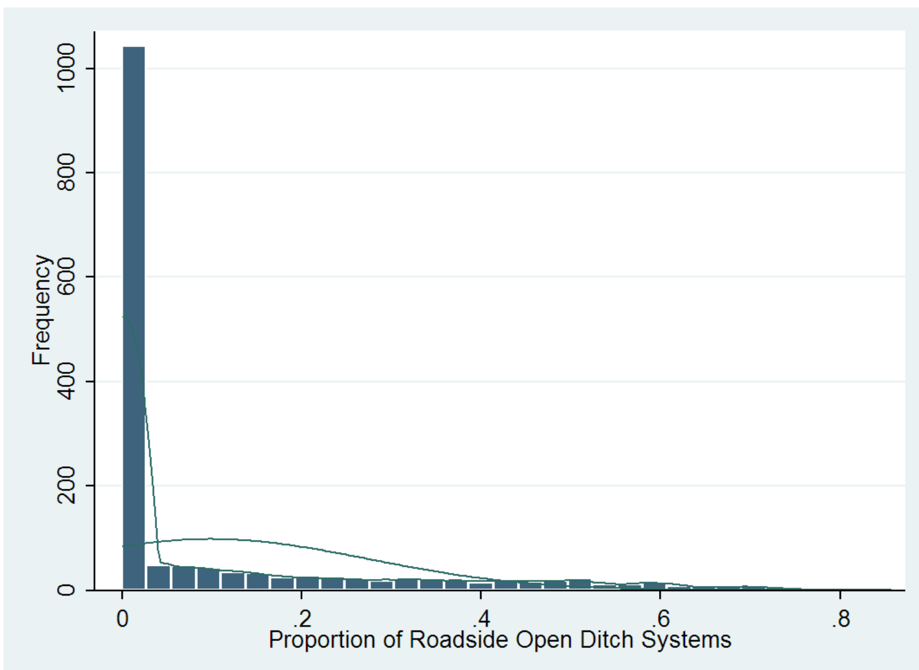

Figure A.1. Histogram of the Proportion of Roadside Open Ditch Systems

Waterproof Missing Data

COH N=1657

COH within Harris County N=1610

Road Data for COH N=1583

Table A.1. Summary of Variables with Missing Data

Variable	Obs=.	Obs>.	Obs<.	Unique Values	Obs<. Min	Max
Proportion of Roadside Open Ditches	27		1,583	>500	0.00	0.86
Household Income	6		1,604	>500	7.65	250.00
Neighborhood Age	18		1,592	67	7.00	75.00
Housing Improvement Value	279		1,331	>500	0.90	1619.04
Vacancy	3		1,607	>500	0.00	62.45

Housing Improvement Variable

Alternative operational tactics were attempted due to outliers in the housing improvement value variable. One method was to truncate the top 1% of improvement values because they were identified as outliers. Likewise, the top outliers were visually identified as mixed-use commercial structures and thus the Improvement values were reflective of the total structure and not individual homes. However, after running the model with the truncated Variable the model was not influenced at all. Another option was to run the model without the outliers but again the model was not influenced, therefore the decision was made to run the model as is with original data including outliers. Also the original data for housing values had zeros but I believe this was missing data and not true values, therefore these zeros were treated as missing and not included in the analysis.

Population Density

Population density and the nature of the formulation of block group boundaries have an inverse relationship. The greater the population, the smaller the area with the boundary, thus increasing the population density and creating outliers. The same process of truncation and dropping missing variables was performed, but original model was kept because model was not influenced.

Additional Methods & Model Results

Theory and Literature guided which confounding variables to include in the model. Next a series of steps for regression diagnostics was done to check for normality, outliers, influentials, etc. Backward elimination was used to develop a parsimonious model. Interaction terms were evaluated for significance individually, and terms with a Wald p-value less that the a priori criteria of 0.20 were retained in the model (Selvin, 2004). Confounding was assessed by removing variables 1 at a time from the model. To maintain a hierarchically well-formulated model, covariates that were part of significant interaction terms were not considered for individual removal from the model for the assessment of confounding or at any other time. Model convergence and predicted probabilities between the values of 0 and 1 were verified. Model selection was informed by comparing -2 log likelihoods of nested models. Following a series of steps including diagnostic box plots, correlations, and bivariate relationships, no covariates were influential enough to consider the addition or removal of any variables. Hispanic was found to be somewhat correlated with household income and influence was seen through the nested models. However, there was no suspicion the experience of Hispanics would be different across income levels. Therefore an interaction term was not used. Also as mentioned above, outliers were identified in two of the confounding Variables (population density and improvement value) and thus different versions of those Variables were tried in the model (truncation and dropping). However, the outliers were not influential enough to considered using alternative forms of those variables.

Lastly, ZIB uses robust standard errors which addresses potential issues with heteroscedasticity. Over 16 combinations of the data were modeled using OLS and ZIB with swapping out potentially problematic confounding variables and between the zero inflation and no inflation. The most fitting model was only marginally influenced at most therefore the original and theoretical model was used for study analysis.